Affective Matter:
A Haptic Material Modality for Emotion Regulation and Communication

by
Athina Papadopoulou

Diploma in Architectural Engineering
National Technical University of Athens, 2008
Post-Graduate Diploma in Architectural Design - Space - Culture
National Technical University of Athens, 2010
SMArchS in Design and Computation
Massachusetts Institute of Technology, 2014

Submitted to the Department of Architecture in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in Architecture: Design and Computation

at the
Massachusetts Institute of Technology

February 2022

Singature of author...
Athina Papadopoulou
Department of Architecture
December 20, 2021

Certified by...
Terry Knight
William and Emma Rogers Professor of Design and Computation
Thesis Supervisor

Accepted by...
Leslie K. Norford
Professor of Building Technology
Chair of the Department Committee on Graduate Students

Dissertation Comittee:

Terry Knight,
William and Emma Rogers
Professor of Design and Computation
Department of Architecture, MIT
Thesis Supervisor

Skylar Tibbits,
Associate Professor of Design Research
Department of Architecture, MIT
Thesis Reader

Leah Somerville,
Professor of Psychology
Department of Psychology, Harvard University
Thesis Reader

Affective Matter:
A Haptic Material Modality for Emotion Regulation and Communication

by
Athina Papadopoulou

Submitted to the Department of Architecture on
December 20, 2021
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Architecture: Design and Computation

ABSTRACT

Our emotions do not always surface into our awareness, making it difficult to put them into words. When emotions do not reach our cognitive awareness they can still express themselves as physiological changes in our body, often unperceived by ourselves and by others. To facilitate emotion regulation and expand the bandwidth of emotion communication, I developed Affective Matter. Affective Matter is a haptic material modality that allows information about the physiological aspects of emotions to be communicated through materials. Through the development of Affective Matter, I aim to enhance intrapersonal and interpersonal affective communication through haptic means and contribute to sensory-based therapies for emotional disorders.

In this dissertation, I first review literature pertaining to emotions and body-mind connections, to support the principles of Affective Matter, including the therapeutic impact of touch and controlled breathing, and the affective impact of interpersonal synchrony. I then discuss the development of two types of programmable affective sleeves as examples of Affective Matter, and describe two controlled studies with human subjects testing the psychophysiological impact of each of the sleeves. The combined results of the studies demonstrate a positive correlation between the sleeves' pace of haptic action and the participants' breathing rates and arousal levels. Finally, I discuss the development of a user interface for material-mediated emotion communication that translates affective information into personalized material haptic action.

Harnessing the sensory properties of matter, this work builds on advances in design, computing, psychology, and materials to propose Affective Matter as a means for human-material therapeutic interaction, where bodies and their material environments can work in synergy to enhance our emotional wellbeing.

Thesis Advisor: Terry Knight
Title: William and Emma Rogers Professor of Design and Computation

ACKNOWLEDGEMENTS

Affective Matter is the end (of the beginning) of a wonderful journey that would not have been the same without the influence, inspiration, and support of mentors, friends, and family. I would like to thank everyone for making this journey purposeful, enjoyable, exciting, and bearable in challenging times.

To my advisor Professor Terry Knight, I am forever thankful for her guidance and confidence in me all those years starting from my Masters and continuing to my PhD degree. Terry has been a great teacher and mentor. She has selflessly supported and productively critiqued my ideas in manner that showed as much care for my personal development as for my creative work. Terry has motivated me to be persistent, methodical, disciplined, and confident about work and ideas. Beyond helping me stay on track on intricate paths of my research journey, Terry has also inspired my work through her own research and the research groups she led. The Computational Making group I have been part of as well as the Reading seminars, inspired me to dig deeper into embodied design approaches focused on the senses and human experience and provided me with the theoretical tools to investigate this research interest further. I would like to thank Terry for the diligent feedback on the dissertation text, and all the guidance and fruitful discussions leading to the dissertation proposal as well as the feedback and support on execution of the dissertation studies. I would also like to thank her for being a wonderful person and know she will keep putting up with me after I get my degree.

To Professor Skylar Tibbits, I am indebted to his generosity and support throughout my years in the Masters and the PhD program. I am deeply grateful for having worked as a Research Specialist at the Self-Assembly Lab before my PhD studies where I progressed significantly as a researcher and developed new fabrication and material research methods skills. The Self-Assembly Lab, which I continued to be affiliated with through my PhD studies, has been for me a magical place that allowed me to really delve into hands-on material experimentation and design innovation. The work I did in the Lab on programmable materials, as well as Skylar’s mentorship, were an inspiration for both my PhD research work and my own development. Working with Skylar has helped me have a clear and strong vision, realistic expectations, and push the boundaries of my discipline.

To Professor Leah Somerville, I owe much of my broader knowledge of emotion theories and science. Leah’s class on emotion at Harvard University, which I attended as a PhD student, as well as her subsequent feedback on my work were very informative and insightful. The productive discussions I had with Leah on my work helped me develop an awareness of how my research methods compare to methods in experimental psychology and equipped me with insights for the future development of my work. I have very much appreciated her patience and eagerness to help me experiment with psychology from my own point of view — that of an architect and computational design researcher eager to delve deeper into emotion research.

To Professor Rosalind Picard, I am deeply grateful for her expert advice on affective computing, her productive critique, and her diligent feedback throughout the development of this work. I sincerely thank her for the time she spent on a thorough reading of this book and her scrupulous comments. The research for this work began as a project for the class Affective Computing taught by Roz at the MIT Media Lab, where I conducted the first of the studies included in this book. The methods of affecting computing I learned in Roz's class equipped me with important research and analytic skills, as I for the first time dealt extensively with affective measurements and physiology data analysis, rigorous user studies, and statistics. Much of the rigor of this book I owe to Roz's class and her subsequent feedback.

To Professor George Stiny, I owe much of the critical questioning regarding my work and my field of research. George's proseminar class (also known as "the salon") on the theory and methods of Shape Grammars, which I attended each and every year of my Masters and PhD studies, has had a great influence on my way of thinking. Much of the philosophical and theoretical inquiry included in this work, as well as my General Examination focusing on the interrelation of the senses, was inspired by thoughts I had in response to discussions in George's class. I am appreciative of George's openness to productively challenge my ideas, and his eagerness to follow my dissertation research until its completion. I am also indebted to the support that George provided as a Director of the PhD Design Computation group.

To Jackie Berry, with whom I collaborated for the first study of Affective Matter, I am very thankful for the creative, fun, and productive time we spend together, as well as the fruitful exchange of skills and ideas which pushed this research forward. I would also like to thank the researchers of the Affective Computing group who helped me and Jackie navigate the technical challenges of physiology measurements and data processing, which were new to us. To all the MIT students and staff who participated in the studies I conducted for my research, I am sincerely grateful as their participation was crucial for the development of my dissertation.

To my past and current PhD colleagues at the Computational Design group in the Department of Architecture, I am very thankful for the shared creative times and productive exchange of ideas: Asli Arpak, with whom I had many intellectually intriguing conversations during my General Examination preparation; Theodora Vardouli, Çağrı Zaman and Dina El-Zanfaly, with whom I shared creative and productive times at the Computational Making group and the Reading group; Diego Pinochet, who, in addition to shared interests, often offered his photography skills to help document both me and my prototypes at work; Lavender Tessmer, for our mutual interests on fabrics and fabrication; Katia Zolotovsky for our shared interest on materials and for giving me opportunity to follow her students' wonderful work; Alexandros Haridis, for the fun times and intellectual conversations. Last, but not least, from the DCG cohort I would like to thank Professor Larry Sass and Professor Takehiko Nagakura for their mentorship to me personally and in the classes they taught for the Design Computation group.

In the administration of the Department of Architecture, I would like to thank the current head Professor Nicholas de Monchaux for his support for the PhD students during the challenging times of Covid-19, and the former head Professor Meejin Yoon, for her support of my research and activities in the department. I would also like to deeply thank Renée Caso for her support and coordination during the challenging times of Covid-19 and for helping me navigate various bureaucracies. I am also very thankful to Inala Locke for her support in regards to my work and activities in the Design Computation group.

During my PhD studies I have had two homes, with some members of the family overlapping. One was the Design Computation group at the Department of Architecture and the other the Self-Assembly Lab at the International Design Center (IDC). I am very thankful to the Co-Directors —along with Prof. Skylar Tibbits— of the Self-Assembly Lab at the time of my studies, Jared Laucks, and Schendy Kernizan, as well as Bjorn Sparrman, former research lead at the Lab. I am thankful for the shared creative times, as well as insights and practical feedback in both the Lab's and my own projects. I am also grateful to IDC's managing staff during my studies, including Deb Payson and Chris Haynes, who kindly supported my activities at the Center.

This work wouldn't have been possible without the love and support of my friends and family. I would like to especially thank my friends Eirini, Eva, Varvara, Theo, Torsten, Maroula, Marialkisti, Hara, and Alexia, among many other good friends who brighten my life. To my mother Hara and brother Nikos, I am forever grateful for the love, support, patience, and confidence in me and my work. Perhaps an inspiration for the remote haptic communication I researched in this work is my need to overcome the physical limitations of the long distance between my family and good friends in Greece, bringing them “one sense closer” through an added haptic material modality in our communication.

To my husband Ivan, I am deeply grateful for his love and support during my long research journey and for the joyful life we have together. I want to thank him for his patience during stressful times, positive energy and confidence in me and my creative endeavors. Being an accomplished software engineer, Ivan provided not only personal support but also mentorship on network systems, in-house code debugging, and active collaboration in developing the system architecture for the second and most extensive study of this thesis.

To my stepson Noah, I am thankful for the joyful times we share that help reset my mind and give a broader perspective on my work and my life. I am always inspired by his positive creative energy. Perhaps more generously and creatively than anyone, Noah has defined my professional identity as the one that “makes things that do not (already) exist.”

I would like to dedicate this work to the memory of my father Xenophon, who once during my childhood brought me to Boston to show me the universities. I never imagined back then that one day I would be one of the MIT PhD graduates standing in front of the dome. The memory of my father’s own journey, full of determination to overcome life’s obstacles and achieve his goals, has never ceased to be a driving force in my own aspirations.

TABLE OF CONTENTS

1.Introduction……………………………………………………..................11

2. Framework for Affective Matter………..……………….................…...23

2.1 (Dis)embodied Emotions…………………………………..........24
2.1.1 The Body in the History of Emotion……………….............24
2.1.2 Body-Mind Connections…………………………………....41
2.1.3 Bottom-Up Regulation Strategies……………………...........49
2.1.4 Interoceptive Awareness…………………………….…..58
2.1.5 Interpersonal Touch, Synchrony, and Empathy…….........64

2.2 Aesthetics of Resonance and Enactive Computations…........72
2.2.1 Empathy as Einfühlung……………………………….......72
2.2.2 Fusion in Action……………………………………........…81
2.2.3 Enaction, Entrainment and Embodiment……………........86

2.3 (Affective) Communication and Self-Regulating Systems…..95
2.3.1 Information Theory and Cybernetics……………….........95
2.3.2 Human-Machine Self-Regulating Systems……..............106
2.3.3 Affective Communication and Computing......................110

3. Affective Matter Studies………………….……….......................…117

3.1 [Study I] Affective Sleeve I: Study on Promoting Calmness in a Stress-Inducing Environment using a Programmable Nitinol-based Sleeve with Haptic Action…………………………….......................................…..….118
3.1.1 Introduction and Scope……………………….............118
3.1.2 Prior Studies……………………………......…...........120
3.1.3 Methods…………………………………………….........122
3.1.3.a The Design of the Affective Sleeve I
3.1.3.b Experimental Method and Hypothesis
3.1.3.c Experimental Procedure
3.1.4 Results……………………………………….........…..136
3.1.4.a Physiological Data Analysis
3.1.4.b Self-Reported Data Analysis
3.1.5 Conclusions……………………………………….........147

3.2 [Study II] Affective Sleeve II: Study on the Affective Associations and Psychophysiological Impact of a Programmable Pneumatic Sleeve with Haptic Action…………………………………....................................150
3.2.1 Introduction and Scope…………………………….......150

3.2.2 Methods……………………………..............................153
3.2.2.a The Design of the Affective Sleeve II
3.2.2.b Electronics Design
3.2.2.c Experimental Method and Hypothesis
3.2.2.d Experimental Procedure
3.2.2.e User Interface and Survey Design
3.2.2.f System Architecture
3.2.3 Results………………………………………………......…192
3.2.3.a Participation and Demographics
3.2.3.b Physiological Data Analysis
3.2.3.c Self-Reported Data Analysis
3.2.4.Conclusions……………………………………………........266
3.2.4.a. Physiological Data
3.2.4.b. Self-Reported Data
3.2.4.c. Overall Conclusions and Future Directions

4. Affective Matter - Connect: An interface for material-mediated emotion regulation and communication, and reflections on mediated social touch………...…...………...............................279
4.1 Introduction and Scope…………………………………….............280
4.2 Mediated Social Touch and the Contributions of AffectiveMatter………...282
4.3 Affective Matter - Connect Interface...289
4.3.1 Lessons Learned from Studies I and II..........................289
4.3.2 Computational Design Principles..................................291
4.3.3 Design and Development..297

5. Conclusions……………………………………….............…...…....319

6. Appendix………………………………………..........................…...341

8. Bibliography...405

1. INTRODUCTION

This dissertation survived the global pandemic of Covid-19. During the pandemic, the necessary social distancing made us more aware of the impact of physical touch on our emotional health. Touch is crucial for our personal development and growth; it is the basis for the development of both psychological growth and interpersonal bonding. Since ancient times, haptic therapeutic treatments have demonstrated their physical and mental health benefits. Yet during the pandemic, any kind of tactile interaction became a viral threat. The pandemic created a hunger for interpersonal touch and for sensory engagement in the world.

The pandemic inevitably imposed limitations to my work. At the same time, the pandemic proved my work on Affective Matter relevant and valuable to our times. I define Affective Matter as a haptic material modality for emotion regulation and communication. Affective Matter consists of wearable materials programmed to provide haptic action based on physiological signals for the purpose of regulating the affective state of the wearer and/or communicating the affective state of one wearer to another. In this dissertation, I explore the impact of Affective Matter on emotion regulation, through the development of two wearable affective sleeves and two controlled studies. I also explore the impact of Affective Matter on interpersonal emotion communication, through a developed user interface that translates affective information into personalized haptic action.

In a context of touch deprivation and social isolation like the one brought on by the pandemic, a haptic material modality could help diminish our mental distress and add the missing haptic dimension to our remote interactions. Although Affective Matter could help us face the mental health challenges of the pandemic, Affective Matter was born out of my own need to understand the bodily language of emotions and my curiosity as to how our environments affect our emotions.

More simply put, the work was born out of my curiosity as to why, at certain times in my student life, when I walked along the Charles River, the heaviness I felt in my chest would gradually subside. I later understood that this heaviness was my body's expression of my emotions. I learned that an affective state of anxiety and stress might often include a feeling of heaviness in the chest and tightness in the gut, shallow breathing, and a fast-paced heartbeat. However, merely becoming aware of the reason for the elephant sitting on my chest did nothing to reduce its pressure. It was the walk by the Charles River that always lifted the load off my chest.

As I will discuss in the next, framework chapter, the cognitive part of our brain does not always have access to our emotions. Because of the architecture of our brains, emotions deeply rooted in our subconscious can have physiological expression in our bodies without surfacing into our awareness. This is usually the case in an anxiety or fear response. The miscommunication between the emotional body and cognitive brain can in fact become so disruptive in certain individuals (for example, in those who have experienced acute trauma) that they become entirely dissociated from their bodily feelings and basic sensory awareness.

When emotions do not surface into our awareness, it is often impossible to manage them by cognitive means or communicate them through language. In such cases, bottom-up sensory regulation methods may help put our bodies and brains back in tune. Haptic treatments like movement exercise and breathing techniques can help bring back our “lost” bodily awareness and regulate it subliminally. Breathing is one function that operates both on the conscious and subconscious level; regulating breathing can help regulate the heart rate and eventually promote calmness.

Different kinds of sensory methods can be used to regulate affective states. My walk along the river is a type of sensory-based emotion regulation method; so is a walk in the woods, a warm bath, or sunbathing on the beach. References to restorative baths can be found in Homeric poems, and references to benefits of hydrotherapy can be found in the writings of Hippocrates and Plato [Gianfaldoni et al., 2017]. Egyptians reported the therapeutic value of sun exposure 6000 years ago; in the eighteenth century, western doctors prescribed “heliotherapy” to their patients [Gianfaldoni et al., 2017; Aldahan et al., 2016]. Recent studies have demonstrated the positive effects of nature on anxiety and depression [Bratman et al., 2015], and research in this direction has even led to the development of what is called “Ecotherapy” [Summers and Vivian, 2018].

Besides natural environments, the environments we design also impact our emotion and behavior. As designers and architects we produce sensory qualities and promote certain affective experiences through the design of the objects and environments we create. The body movements that a building suggests, the social interactions that it affords, the lighting, textures, and overall atmosphere it creates, all affect our mood. When we design an object or building, we orchestrate the qualities of our natural environment to create a new environment that can have as great an impact on our emotions as nature.

The sentiment that architecture is a form of affective experience, rich in sensory stimulation, is a sentiment that most, if not all, great architects would agree with. The renowned Swiss architect Peter Zumthor often writes about how architectural atmospheres shape our affective experiences. In his book Thinking Architecture, Zumthor [2010, p. 7] gives a vivid description of the affective experience of a building:

> "There was a time when I experienced architecture without thinking about it. Sometimes I can almost feel a particular door handle in my hand, a piece of metal shaped like the back of a spoon. I used to take hold of it when I went into my aunt's garden. That door handle still seems to me like a special sign of entry into a world of different moods and smells. I remember the sound of the gravel under my feet, the soft gleam of the waxed oak staircase, I can hear the heavy front door closing behind me as I walk along the dark corridor and enter the kitchen, the only really brightly lit room in the house."

In recent decades, extensive research has been conducted on the affective aspects of materials on product design and user experience. The studies focus on the attribution of affective qualities to products, usually with the aim of aiding designers to better communicate their design intentions and respond to consumer and market needs [Desmet and Hekkert, 2009; 2007; Karana et al., 2014]. Despite testimonies from experienced architects and phenomenological writings such as those by Finnish architect Juhani Pallasmaa [1996; 2011], discourse on materiality, senses, and emotions remains limited in the discipline of architecture.

All environments are affective environments, but great architecture and design can orchestrate certain physical and affective material qualities in such a manner as to produce rich, positive sensory experiences. I argue that in a way similar to how we as architects and designers can promote certain desired experiences through the spaces and objects we design, we can orchestrate certain sensory, environmental qualities through the design of affective material environments to enhance our emotional wellbeing. We can program our interactions with material environments to allow a sensory feedback loop between our bodies and materials to regulate our affective states.

I suggest that we design our environments to interact with our bodies for the purpose of regulating our emotions as a non-noninvasive and non-pharmacological method to enhance our emotional wellbeing, as it can be achieved by harnessing sensory material qualities. Affective Matter offers a programmed therapeutic interaction with our material environments, which nevertheless relies on simple sensory environmental properties, as does a walk along the river, or a warm bath. To make material environments interact with our bodies in a desired, programmed manner, I utilize a specific method that relies on the relationship between rhythmically produced material sensations and our bodily rhythms.

Affective Matter takes advantage of the body's tendency to synchronize its own rhythms and to synchronize with the rhythms of the environment. In the process of understanding and empathizing with one another, humans tend to synchronize their body posture and physiology, a phenomenon called interpersonal or physiological synchrony, emotional contagion, or, more broadly, entrainment [see chapter 2.1.4; 2.1.5]. The important discovery of mirror neurons also shows that to understand an action, we may physically simulate it in our own body. We have experienced the impact of interpersonal synchrony since we were newborns, when we adjusted our breathing and heart rhythms to that of our mother or father while lying on their chest.

We do not synchronize our rhythms only with those of other humans; we also synchronize our bodily rhythms with the rhythms of our physical and material environments. Every day of our lives, we synchronize our circadian rhythms based on the cycles of day and night; when we dance, we synchronize our movement to the beat of the music or to the steps of our partner. Synchronization also occurs in the process of experiencing an artwork or natural object, a process termed Einfühlung in eighteenth century German aesthetics [see chapter 2.2.1]. Current theory in design computation also discusses the fusion and interactive dialog that occurs between creator and artifact during the creative process [see chapter 2.2.2].

This tendency we have to synchronize with our environments can be utilized to create environments that regulate our emotions. Recent studies have already shown that providing rhythmic sensory feedback has an impact on one's affective state [Costa et al., 2016; Ghandeharioun and Picard, 2017]. For example, Ghandeharioun and Picard [2017] demonstrated that auditory and visual stimuli on the computer screen, rhythmically oscillating to match relaxed breathing rates, can reduce stress levels. In Affective Matter, I expand the research on sensory-based regulation in material environments with haptic action. I also extend the application of synchronicity in the embodied interaction with our environments to address interpersonal emotion regulation and communication.

Looking for a sensory-based emotion regulation and communication method, I chose to focus on materials –instead of, for example, digital interfaces or ambient environmental interactions-- for three reasons. The first reason is that through the sensations of warmth and pressure, haptic material properties can offer therapeutic benefits. The second reason is that materials make up our physical world; we use materials to fabricate our environments and everyday objects. Demonstrating a method for emotional wellbeing based on matter can open up possibilities for designers to create objects with health benefits. The third reason is that the advanced materials of today, and the ability to program their behavior, allow us to have a high degree of control over materials' sensory and affective qualities and the way these influence the relationship between humans and their environments.

As architects and designers, we are used to manipulating matter and developing material techniques by testing and iterating our solutions. If in the repertoire of materials we use to design things we add parameters regarding their affective properties, we can have a more targeted pool of options when designing for emotional health and wellbeing. Studies in the area of product design, materials, and sensory perception have already begun documenting the associations between materials, sensory, and affective qualities [Etzi and Gallace, 2016; Wilkes and Miodownik, 2018; Grippa et al, 2012].

Programmable materials are already being used for the benefit of user customization, manufacturing and shipping, fashion design, sportswear applications, art installations and adaptive shading [Tibbits, 2017; 2021]. Types of electroactive polymers and inflatable materials are being tested for biomedical applications because of their ability to act as artificial muscles [Bar-Cohen, 2002; Ramasamy et al., 2007; Belforte et al., 2014]. Research on programmable materials has also been extensive in the field of human-computer interaction [Ishii et al., 2012; Wiberg, 2018]. However, we can now go further into the programmable materials research to design programmable materials that interface with the human body to enhance emotional health.

Before embarking on the Affective Matter journey, I had the opportunity to work as a researcher at the MIT Self-Assembly Lab, where we developed a variety of temperature-responsive programmable materials. Having this experience was an important resource and inspiration in the material exploration aspect of this dissertation. In the early stages of my dissertation research, I created a series of mockup diagrams depicting possible ways that physiological signals could be used to control material transformation by being converted to heat; I made collages of photos of programmable material we had produced at the MIT Self-Assembly Lab along with diagrams I developed. The collages depicted possible electrical connections between materials and the body and hypothetical material transformations corresponding to the body's physiological response [FIG 1-2].

For the purpose of this dissertation, I developed two programmable sleeves, each used in a controlled study. The first sleeve was made from nitinol, a shape memory alloy, and fabric. When current passes through the nitinol wires held in a curved shape through the mechanical tension of elastic bands, the wires straighten, causing the sleeve to change shape. The shape change produces a sensation of light pressure, while the current produces warmth. The second sleeve was made from inflatable fabrics with embedded heat pads, based on a design I developed that optimizes the curvature around the forearm upon pressurization. The sleeve causes the feeling of pressure upon inflation and the feeling of warmth when current passes through the embedded heat pads.

The two programmable sleeves were conceived as “minimum” material environments (as opposed to larger scale material environments such as a body suit or a built space) that can interact with the body through sensory means. In a similar way that our body is responsive to changing weather -- relaxing or stiffening our muscles, opening or closing the pores our the skin, and relaxing or focusing our mind – our body is also responsive to the micro-environments created by the sleeves, interacting with the sensory qualities they produce and responding physically and psychologically. I chose to develop wearable environments as these can interact with the body through haptic means.

Even though my intention was for the sleeves to be perceived as wearable environments, many may perceive them as wearable devices. Today we see an abundance of wearable devices, usually in the form of wristbands or smart watches that can measure vital signals and inform the wearers about their physiological state. The difference between the affective sleeves I developed and the aforementioned devices is that in addition to recording one’s vital signals, the sleeves physically respond to these signals through haptic action in order to change the affective state of the wearer. I use the term wearable environment to emphasize this difference.

The first study [chapter 3.1] focuses on material-mediated emotion regulation via a programmable nitinol-based sleeve, testing in a controlled experiment to determine whether it can reduce the psychophysiological symptoms of stress. The sleeve is programmed to produce haptic action at a pace correlated with participants’ relaxed breathing rate. The second, and more important, study [chapter 3.2], focuses on material-mediated emotion regulation via a programmable pneumatic sleeve, testing the psychophysiological impact of different conditions of haptic action.

The combined results of the studies suggest a positive correlation of the pace of haptic action with participants’ breathing rate. The results also suggest a positive correlation between subjective arousal levels and the pace of haptic action. In particular, a slow pace of haptic action is associated with states of low arousal, including feelings of calmness or tiredness, and a fast pace of haptic action with states of high arousal, including feelings of stress (study I) or excitement (study II). The second study also demonstrates some haptic conditions as more effective than others and a different perception of sensory intensity

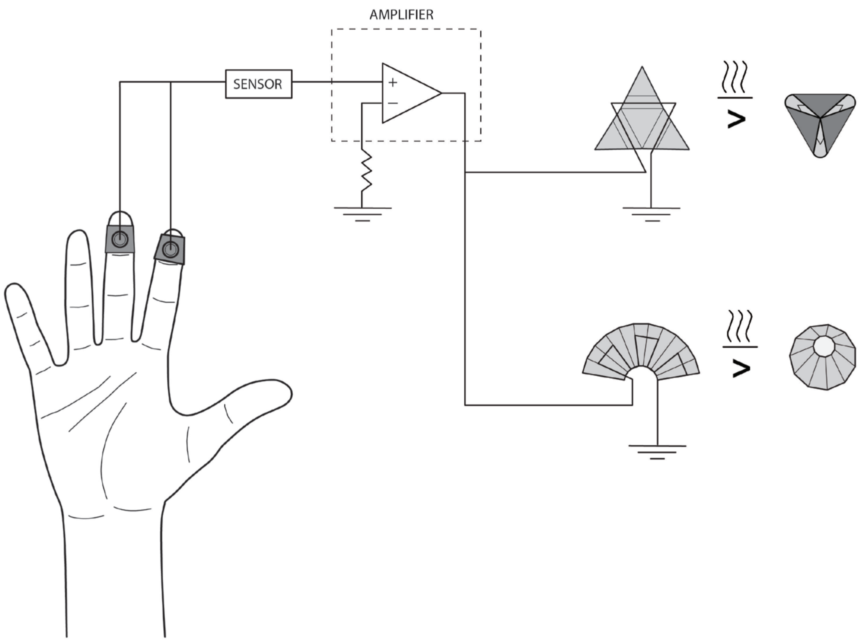


FIG 1. Conceptual diagram I made of electrical connections depicting programmable shape transformation based on amplified levels of electrodermal activity

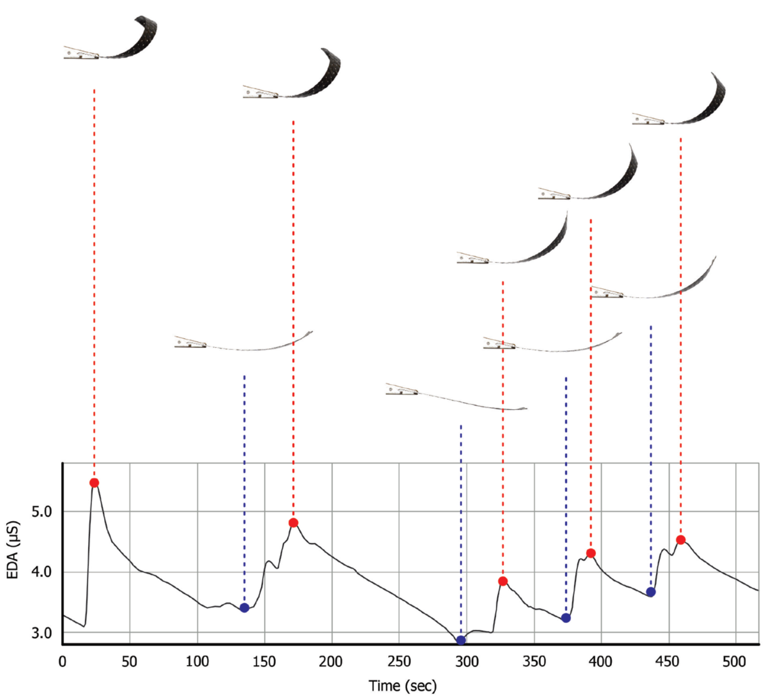


FIG 2. Conceptual diagram I made depicting programmable shape transformation based on peak response values of electrodermal activity

based on the pattern of haptic action. It also suggests certain pleasant or unpleasant associations for specific patterns and paces of haptic action. The identified differences in the affective response to varied haptic stimuli contribute to the research of material-mediated interpersonal communication.

The exploration of material-mediated interpersonal communication is focused on the development of a user interface [chapter 4]. The interface allows for user customization of the haptic parameters of an affective sleeve or other wearable environment to address personal preferences and sensory sensitivities. It also allows for customized mapping of the haptic parameters and affective evaluations. In this manner, material-mediated communication takes into account subjective evaluations for the translation of affective information. The interface also explores the communication of different kinds of affective information via Affective Matter as well as personalized emotion regulation based on the parameters set by the user.

Material-mediated emotion regulation via Affective Matter works by programming the haptic action of the materials according to measured physiological signals – in the case of the conducted studies, breathing activity. The haptic action is produced through material actuation (inflation or temperature-responsive shape change) in order to produce a feeling of pressure, and by passing current through the sleeve (through the heat-pads or metal wires) in order to produce a feeling of warmth. Because the pace of the rhythmic haptic action correlates with the pace of the breathing activity, as shown in my studies, it eventually regulates breathing, impacting one's affective state.

Through the design of the Affective Matter interface, I address how material-mediated interpersonal emotion communication via Affective Matter can potentially occur when two or more individuals who both wear a programmable sleeve (or other wearable environment) exchange information regarding their physiology through the sleeves. With the aid of the interface, physiological signals of the first person are translated into haptic action in the sleeve of the second person, and physiological signals of the second person are translated into haptic action in the sleeve of the first person. Through this haptic material modality for communicating affect, I envision that two connected individuals could "feel" each other, exchanging information regarding their affective state non-verbally.

As mentioned earlier, our cognitive awareness does not always have access to our emotions, yet cognitive therapies rely on spoken language. However, we are often unable to communicate our feelings through language. This is especially the case for individuals with developmental disorders who also have emotional disorders. Such individuals are often not as eloquent as neurotypical patients and sometimes are not even verbal, as in the case of many individuals on the autism spectrum. A non-verbal haptic modality for communicating emotions can in principle allow us to communicate our feelings without having to put them into words, potentially contributing to inclusive therapeutic methods.

In the context of Affective Matter, emotion self-regulation and affective exchange between two or more individuals are considered types of emotion communication. The former is a case of intrapersonal material-mediated emotion communication and the latter is a case of interpersonal material-mediated emotion communication. When our cognitive brains become disconnected from our emotions, which are nevertheless expressed in our bodies, Affective Matter can mediate between our bodies and our brains through the process of entrainment. Interpersonal material-mediated communication also operates through the process of entrainment, through the synchronization of the bodily rhythms of two individuals and the material environment that mediates between them. My goal in developing Affective matter is to help us become in tune with ourselves and others.

In addition to the description of the studies, this dissertation includes an extensive theoretical framework [chapter 2]. The framework is divided into three chapters, each of which addresses the main areas of investigation that underlie my work: emotions, arts and design computation, and self-regulating and affective systems. The framework focuses on scientific studies and theories pertaining to emotions and the body that support the premises of this dissertation and inspired its development and execution. I also aim to create a dialog between the theoretical principles of my methods and the ideas on embodiment and the senses often discussed at the MIT Design Computation Group. Finally, I aim to situate my work in reference to current and past seminal computational approaches to the regulation of emotions and the body.

The first section of the framework chapter [chapter 2.1], entitled (Dis) embodied emotions, is divided in five parts: In the first part, The body in the history of emotions [chapter 2.1.1], I describe how for centuries, emotions were considered disturbances arising from the body that needed to be disciplined by the mind. It was not until the late nineteenth century that the body and its physiological processes became a significant part of emotion theories and studies. In the second part [chapter 2.1.2] entitled Body-mind connections, I address the role of emotion in consciousness in Antonio Damasio's embodied neuroscientific approach [Damasio, 1994/2005; 2000], and embodied approaches to mental health in Bessel van der Kolk's work on trauma research [Van Der Kolk, 2015].

In the third part of (Dis)embodied emotions, entitled Bottom-up regulation strategies [chapter 2.1.3], I discuss the roles of the sense of touch and breathing in emotion regulation. In the fourth part, entitled Interoceptive awareness [chapter 2.1.4], I discuss how limited interoceptive awareness, which is the awareness of our internal bodily functions, is associated with limited emotional awareness and mental health disorders. In the fifth part, Interpersonal touch, synchrony, and empathy [chapter 2.1.5], I discuss the impact of interpersonal touch on personal growth and interpersonal bonding, and how interpersonal synchrony is associated with empathy and action understanding.

The second section of the framework chapter is titled Aesthetics of resonance and enactive computations [chapter 2.2] and is divided into three parts. In the first part, Empathy as Einfühlung [chapter 2.2.1], I discuss the initial definition of empathy as introduced in German aesthetics at the end of the nineteenth century, when it was used to describe the resonance that occurs between an individual and the object of art or nature they are experiencing. In the second part, Fusion in action [chapter 2.2.2], I discuss embodied, sensory-focused, approaches in design computation, particularly in the Shape Grammar and Making Grammar frameworks. In the third part, entitled Enaction, entrainment and embodiment [chapter 2.2.3], I discuss how the notions of enaction, entrainment and embodiment define dynamic adaptive systems.

The third section of the framework chapter, entitled (Affective) communication and self-regulating systems [chapter 2.3], is divided in three parts. In the first part, Information Theory and Cybernetics [chapter 2.3.1], I review postwar theories of communications and models for self-regulating, adaptive feedback systems. In the second part, Man-machine self-regulating systems [chapter 2.3.2], I discuss applications of cybernetic self-regulating models to the human body. In the third part, Affective communication and computing [chapter 2.3.3], I discuss several past and current seminal computational approaches on emotion processing and communication, focusing on the temporal dimension of emotions.

As will be discussed in the framework chapter [chapter 2.3], in the era of Cybernetics, the fantasy motivating engineers and scientists was to build self-regulating, human-machine systems. In this man-machine paradigm, the human organism was regarded as a “black box” whose behavior could be adapted by tweaking its sensors and actuators. In its extreme, the man-machine paradigm became Clyne’s cyborg; a biologically augmented individual with integrated exogenous devices that allowed for self-regulation and adaption to new environments. The man-machine paradigm faded away, when, with the further development of cognitive science and AI systems, we realized that -- as Picard [1997/2000] points out in Affective Computing -- we need to adapt machines to humans and not humans to machines.

Although our research and imagination are no longer driven by the man-machine paradigm, I argue that, when we choose to rely solely on pharmacological solutions to respond to emotional challenges that cannot be resolved through words ---without suggesting that this is what psychiatry aims for— we still treat ourselves as black-box machines. This dissertation builds upon advances in design, computing, psychology, and materials to shift the paradigm from human-machine systems to human-material affective systems, where bodies and their material environments can work in synergy to enhance our emotional wellbeing.

2. FRAMEWORK FOR AFFECTIVE MATTER

2.1. (DIS)EMBODIED EMOTIONS

2.1.1. THE BODY IN THE HISTORY OF EMOTION

Since ancient times there has been much debate among philosophers and scientists regarding the nature of emotions. The term "emotion" is fairly new in the history of humanity; it is a modern construct that emerged as part of the development of the field of psychology. The first appearance of the word "emotion" in the English language was in Hume's writings, and it is believed that he borrowed the term from Descartes [Dixon, 2003][1]. Interestingly, people in the middle ages and ancient times did not "have emotions"; instead they had "feelings," "affects," "desires," and "passions." These terms were usually seen as subordinate to reason, with the body considered to be the unruly part of the soul or at best a mere medium of its expression.

Before the 17th century, emotions were part of a broader discourse on the soul or human experience, which included the senses and other bodily feelings like hunger and thirst. The term "emotion" appeared together with systematic attempts to categorize feelings and affects into precise categories and relate them to mental illness. Nevertheless, histories of theories of emotions began with theories in ancient Greece, as many of the feeling-related concepts and attributes used in the psychological theories of emotion today can be found in these early philosophical texts [Knuuttila, 2018] [FIG. 3 - 4].

In Republic, Book IV, Plato [trans. 2003] describes the State he envisions as having the qualities of wisdom, courage, discipline, and justice, and defines the qualities of a member of that State in accordance with the qualities of the State: in the same way the different parts of a society should work in harmony and avoid conflict, the different parts of an individual should also be in harmony and maintain a proper order. Plato describes the different three parts of the soul: Reason. the rational part (logistikon); (2) Spirit, the spirited part (thumoeides), and (3) Appetite: the appetitive part (epithumetikon).

The rational part of the soul includes the ability to understand, think, calculate and make decisions. The spirited part includes qualities like indignation, courage, and determination. The appetitive part includes

---

1 Etymologically "emotion" derives from the French word emouvoir which means to stir up, from Old French esmovoir, from Latin word emovēre which meant remove, displace (from e- + movēre to move). See Merriam-Webster. (n.d.). Emotion. In Merriam-Webster.com dictionary. Retrieved April 9, 2021, from https://www.merriam-webster.com/dictionary/emotion

instinctive desires and passions. Although Plato discusses how the three parts should be in harmony and not in conflict with one another, there is an explicit hierarchy among them, with the rational part mastering the rest and the appetitive part coming last in rank. According to Plato, when reason rules, people behave in the right way, whereas if impulses are left uncontrolled people can exhibit disturbed behaviors, immediate desires, or aggression.

An important aspect of Plato's discourse on emotions influencing western views on emotions is the belief that emotions were the lower part of the soul that should be tamed by reason. In the State envisioned in the Republic, according to Plato, the individual is disciplined (and therefore just) when his Spirit and Appetite follow the orders of Reason: "Then don't we call him [the individual] self-disciplined when all these three elements are in friendly and harmonious agreement, when reason and its subordinates are all agreed that reason should rule and there is no civil war among them?' [Plato, trans. 2003, 442c-d]

According to Plato it is the Appetite (the desires and passions - our direct emotions) that is the lowest part of all. In the following passage Plato describes how Reason trains Spirit and then in their turn both discipline Appetite:

> "When these two elements have been so brought up, and trained and educated to their proper function, they must be put in charge of appetite, which forms the greater part of each man's make-up and is naturally insatiable. They must prevent it from taking its fill of the so-called physical pleasures, for otherwise it will get too large and strong to mind its own business and will try to subject and control the other elements, which it has no right to do, and so wreck the life of all of them" [Plato, trans. 2003, 442a-c]. In short, according to Plato, an individual driven by their emotions is sure to be dangerous to themselves and others.

The most extensive of Aristotle's discourse related to emotions is his Rhetoric, which is a discourse on speaking and the art of persuasion. Aristotle does not use the word "emotion," because, as mentioned, the word had not been invented yet; instead, he uses the word pathei, which is most appropriately translated as affections (although many modern translators translate it as emotion). Aristotle writes in regard to affections / pathei: "The affections are things through which, changing, men differ in their judgements, and which are followed by pain and pleasure, such as anger, pity, fear, and other such things, and the opposites of these" [Aristotle, trans. 2018, 2.1.1378a6-20]. Aristotle discusses how when inducing certain emotion to someone, their thoughts change accordingly, and this is the reason why we need to know about emotions when it

FIG 3.
Communication of emotions in ancient Greece: Greek tragedy mask. 4th cent. B.C. Piraeus, Archaeological Museum. Source: Wikimedia / Creative Commons

FIG 4.
Communication of emotions in ancient Greece: Theatre mask made of pentelic marble. Possibly a comedy character 2nd-century B.C. National Archeological Museum of Athens. Source: Wikipedia / Creative Commons

comes to public speaking.

Under the term pathei Aristotle describes at length a series of affective states explaining the situations in which emotions arise and their intentionality. For example, Angry are the men who feel they have been wronged or mistreated and they are angry at the person who wronged them; Fear is “a feeling of pain and disturbance accompanying a mental image of imminent evil of a life-threatening or painful kind” [Aristotle, trans. 2018, 1382a21–2]. For every emotion, Aristotle defines its opposite, and although the list is not intended to be exhaustive, Aristotle describes the following oppositional pairs of emotions: anger and placability, love and hate, fear and confidence (in Greek tharos, whose meaning is closer to that of courage), shame and shamelessness, benevolence and churlishness, pity and resentment; envy seems to be described as the opposite of emulation, and emulation is described as the opposite of contempt.

In addition to aspects of evaluating emotions, in his De Anima Aristotle discusses, although in not much length, emotions in terms also of their physical aspect: “It seems that all the affections are of it with body, as anger, mildness, fear, pity, hope and even joy and loving and hating. For in all these cases the body is affected in some way” [Aristotle, trans. 1986, 1.1.403a16-19]. He also gives an example regarding the emotion of anger, discussing that is a particular motion of the body, describing it as the “boiling of the blood and hot stuff around the heart.” [Aristotle, trans. 1986,1.2.403a-b]. Aristotle definitely saw an embodied aspect to emotions, although for him, as for Plato, cognitive evaluation precedes bodily expression.

As was the case in ancient times, the Stoics regarded emotions as (products of) mistaken judgments that lead to pain and suffering [Stellars, 2014]. Stoics aimed at state called apatheia, literally translated as “the absence of passions.” It is through “apatheia” that Stoics believe that one can achieve eudaimonia, a state of moral wellbeing (Virtue). By regarding emotions as judgements Stoics aimed at the complete rational control of irrational disturbances of the body –the first impressions over which we have no control. Seneca, a Roman Stoic philosopher, discussed emotion as follows:

> “Emotion does not consist in being moved by the impressions that are presented to the mind, but in surrendering to these and following up such a chance movement. For if any one supposes that pallor, falling tears, sexual excitement or a deep sigh, a sudden brightening of the eyes, and the like, are evidence of an emotion and a manifestation of the mind, he is mistaken and fails to understand that these are just disturbances of the body.”

[Seneca, On Anger. Quoted in Stellars, 2014, p.115]

The Stoics and Epicureans also used the term "ataraxia" which can literally be translated as a "state with no disturbance" and was first used in the philosophy of Pyrrho. The Internet Encyclopedia of Philosophy (IEP) discusses ataraxia as "imperturbability, literally "without trouble," sometimes translated as "tranquillity"; a state of mind that is a constituent of the eudaimôn life. It defines "apaheia" as "freedom from passion, a constituent of the eudaimôn life." Epicurus uses the term passion (πάθος) to define three capacities by which we know the world: sensations (αισθήσεις), preconception (προλήψεις) and passion. Epicureans argued that pleasure (ηδονή) and pain (αλγηδών) exist in every animal, function automatically and do not depend on Reason (λόγος) [Konstan, 2006]; they are irrational parts of the soul, as are sensations.

In philosophies developed as part of classic Christian theology, the need of the reason to control the passions as bodily disturbances became more evident and the separation between the mind and body more strict. The mind was part of the immortal immaterial soul and the passions were part of the mortal sinful lower part of the soul, expressed in the material body. St Augustine of Hippo and St Thomas Aquinas were the most prominent figures of the Christian Theology. In regards to what we today call "emotions" Auguste and Aquinas distinguished between two different categories one belonging to the lower and one to higher soul. The passions and the appetites belonged to the lower part of the soul, whereas affections belonged to the higher part of the soul [Dixon, 2003].

The appetites in Christian theology were hunger, thirst and sexual desire. The passions in Christian theology were love, hate, fear and anger. The appetites and passions were a form of punishment for the original sin of Adam and Eve. However, love as a higher affection, sympathy, and joy were signs of connection to God. Augustine separated humans into an inner and an outer part, the inner being the intellectually superior part and the outer being the corporeal subordinate part. For Augustine, all humans were divided between their inner and outer part, the inner being struggling to control the outer one. The struggle was due to our "fallen state," which resulted in humans being disordered. The distinctions between a corporeal and incorporeal part were also influenced by Neoplatonic ideas on the unchanging forms of ideas and their inferior material impressions [Dixon, 2003].

Aquinas also followed distinctions of the soul into a higher immaterial part and a lower irrational part. In addition, he categorized the faculties of the soul in terms of their struggle and success, motion and rest. Success and rest were discussed as the ultimate goals. Within the soul, Aquinas distinguished between the higher intellect and will and the lower appetite. The lower appetite could be moved by passions such as hope, despair, fear, courage, anger, love, hate, desire, aversion, pleasure and sadness. The need of the rational part to rule the irrational part, evident in the writings of Augustine and Aquinas, is very well expressed in Augustine's The Free Choice of the Will in which he describes a human taken over by their evil passions:

> "Passion (libido) lords it over the mind, dragging it about, poor and needy, in different directions, stripped of its wealth and virtue ... And all the while, the cruel tyranny of evil desire holds sway, disrupting the entire soul and life of man by various and conflicting surges of passion (libido); here by fear, there by anxiety; here by anxiety, there by empty and spurious delights; here by torment over the loss of a loved object, there by a burning desire to acquire something not possessed ... On every possible side the mind is shriveled up by greed, wasted away by sensuality, a slave to ambition, is inflated by pride, tortured by envy, deadened by sloth, kept in turmoil by obstinacy, and distressed by its condition of subjection. And so with other countless impulses that surround and plague the rule of passion" [Dixon, 2003 loc. 695-698].

In the 17th and 18th century, discussions on emotion and the soul were replaced by discussions of human nature, and then eventually replaced by modern debates on physical aspects of emotions including physiological expressions and their neuronal patterns. However, the distinction between mind and body, rational thinking and irrational affections, continued to develop, albeit in a more scientific spirit. For Descartes passions were a special kind of perception caused by the agitation of the "animal spirits" in the body (animal spirits were parts of the blood). The division between mind and body became more literal in Descartes through the definition of the thinking substance of the soul and the extended substance of the physical body. Instead of an emotion model grounded on religion, a model often used in the eighteenth century was that of a machine, inspired by the industrial "zeitgeist." Hobbes used the machine metaphor in Leviathan:

> "For seeing life is but a motion of limbs, the beginning whereof is in some principal part within; why may we not say, that all automata (engines that move themselves by springs and wheels as loth a watch) have an artificial life? For what is the heart, but a spring; and the nerves but so many strings; and the joints but so many wheels, giving motion to the whole body, such as was intended by the artificer?"' [Dixon, 2003, loc.1225-1226]

By 1850, most theorists used the term "emotions" as an umbrella term that covered, and eventually replaced “affections,” “passions,” “feelings,” “sentiments,” and other terms previously used to denote the subtle differences of emotional experience. The elimination of such terms or the use of them as mere synonyms led to many misunderstandings regarding ancient and medieval theories [Dixon, 2003]. The use of the term “emotions” as a suitcase word for affective processes, according to Dixon [2003], was due to the secularization of the philosophies of mind and the formation of psychology as a scientific discipline. Dixon argues that although we understand the history of emotions as focused on the mind-body relationship, with the former controlling the latter, if we appreciated the nuances of the many terms used prior to “emotions,” (that got eliminated through translations and interpretations in various emotion histories), we would think otherwise. Even if we keep those subtleties in mind, however, we see there is a clear preference for cognitive driven-theories, the exception being the Empiricists and Sensationalists in the 18th and 19th centuries.

During the 18th and 19th centuries, theories about the mind -- and by extension the emotions -- were indeed divided. On the cognitive end of the spectrum were philosophies on “a priori knowledge,” and on the embodied end were the Empiricists, Associationists and Sensationalists [Dixon, 2003] The cognitive end of theories of mind, influenced by Kant, argued that all experiences derived from mental models, whereas the empiricists referred to the philosophies of Locke, Berkeley and Hume, who believed that all ideas derived from sensory experience. Sensationalists were more extreme than empiricists in that they declared that we are nothing but sensations. An example of sensationalism was Cadillac’s Treatise on the Sensations, where a statue gradually comes alive through the sequential activation of each of the senses [Condillac, 1754/2000].

David Hume’s work on the history of emotions is important, as he was the first to use the word “emotion” in the English language. Hume possibly borrowed the term from Descartes [Dixon, 2003]. Another, more important reason why Hume’s work is important in the history of the theories of emotions is because he inverted the classic dualism of Reason vs Passion in Plato’s philosophy and Christian theologies. Hume asserted that “Reason is, and ought only to be the slave of the passions, and can never pretend to any other office than to serve and obey them.” According to Dixon [2003], Hume’s position was radical for two reasons: first, because it inverted the classic hierarchy that requires reason to govern the passions and appetites and second, because it expressed the view that the mind was a stream of passions and desires.

In the second half of the 19th century, theories about emotion took further distance from theological models and abstract conceptions of the soul to focus on physiological and evolutionary aspects of emotions. Alexander Bain, Herbert Spencer, and Charles Darwin are the three names most discussed as establishing this physical turn. Although Bain and Spencer were very influential at their time, Darwin's theories ended up being more popular in later discussions, and it is Darwin who is currently referred to as a precursor of certain modern emotion theories. In Bain's, Spencer's and Darwin's work, the body was given more importance than before, as the different physiological aspects of emotions were studied [Dixon, 2003].

In the theories of Bain, Spence and Darwin, the body was no longer seen as a mere instrument of the emotional mind, but an active agent in emotional behavior. It was still, however, the brain that dictated the rest of the body, prioritizing the activity of brain neurons over bodily feelings. For example, Bain in Body and Mind (1873), described the emotion of fear as follows:

> "When a shock of fear paralyses the digestion, it is not the emotion of fear, in the abstract, or as a pure mental existence, that does the harm; it is the emotion in company with a peculiarly excited condition of the brain and nervous system; and it is this condition of the brain that deranges the stomach" [Dixon, 2003, loc. 1916-1918].

Darwin, building upon the work of physiologists of the time, further expands the discourse on the physiological manifestation of emotions. In addition, he aims to explain the physical expression of emotions and trace their roots in accordance with his theory of evolution. His work on the expression of emotions is not a theory of emotions per se, but has greatly influenced theories of emotions to this day. In The expressions of emotions in man and animals published in 1872, Darwin defines the main principles of the expressions of emotions and gives detailed examples of observed expressions of animals and humans from different races and cultures, aiming to prove that there are some basic emotions that are universal in their expression, innate and inherited [Darwin, 1872/2009].

Darwin is not primarily interested in the "expression" of emotions as a mode of communication. For Darwin emotions are hardwired physical instinctual or habitual actions that serve some survival purpose or desire, or instinctual reflex reactions: their primary purpose was never meant to be communication (except for some more recently developed expressions and gestures, such as the nodding and shaking of the head as a means of affirmation and negation, or the hands in the form of prayer, that he discusses as commonly shared among cultures but not as universal). Regarding the emotions as "expressions", Darwin writes:

> "Actions of all kinds, if regularly accompanying any state of mind, are at once recognized as expressive. These may consist of movements of any part of the body, as the wagging of a dog's tail, the shrugging of a man's shoulders, the erection of the hair, the exudation of perspiration, the state of the capillary circulation, laboured breathing, and the use of the vocal or other sound-producing instruments. Even insects express anger, terror, jealousy, and love by their stridulation." [Darwin, 1872/2009, p.321]

The fact that Darwin includes even the insects in providing grounds for an evolutionary theory for the expression of emotions, is in interesting opposition to ancient and medieval emotion theories that saw refined human emotions as being of a higher form than those of animals and believed that disturbing passions corrupting the soul were of an animalistic nature. Darwin is not concerned with any distinctions pertaining to consciousness or cognitive evaluations, as for him emotions for all beings are the results of physiological patterns following certain states of minds. Darwin's expression of emotions follows three principles: (1) The principle of serviceable associated habits; (2) The principle of Antithesis; and (3) The principle of actions due to the constitution of the Nervous System, independently from the first of the Will, and independently to a certain extent of the habit [Darwin, 1872/2009].

According to the principle of serviceable associated habits, some bodily actions began to be used because they were useful when in a certain state of mind, and then became associated with that state of mind. Now, even if these actions are no longer useful, they are still tied to the specific emotion. These are actions that become inherited and can have the nature of a reflex action even through initially they were used for a specific purpose. Indicative of this principle is Darwin's description and explanation of the expression of emotions of disdain, contempt, and disgust: the nose is contracted followed by a short expiration, and the lips are protruded, both actions aiming unconsciously to close the nasal passage, as we do when we perceive a bad odor; It is as if we say to "the despised person that he smells offensively" [Darwin, 1872/2009, p.233].

Like disdain and disgust, the states of mind of astonishment, fear, and horror are also expressed physically and physiologically. Interestingly, Darwin sees emotions as different states in a certain transformation of the body where one kind of emotion graduates into another:

> "Attention, if sudden and close, graduates into surprise; and this into astonishment; and this into stupefied amazement. The later state of mind is closely akin to terror. Attention is shown by the eyebrows being slightly raised; and as this state increases into

FIG 5.
"Head of snarling Dog" Image from Darwin's *The Expression of the Emotions in Man and Animals*. Source: Wikimedia Commons/ Public domain

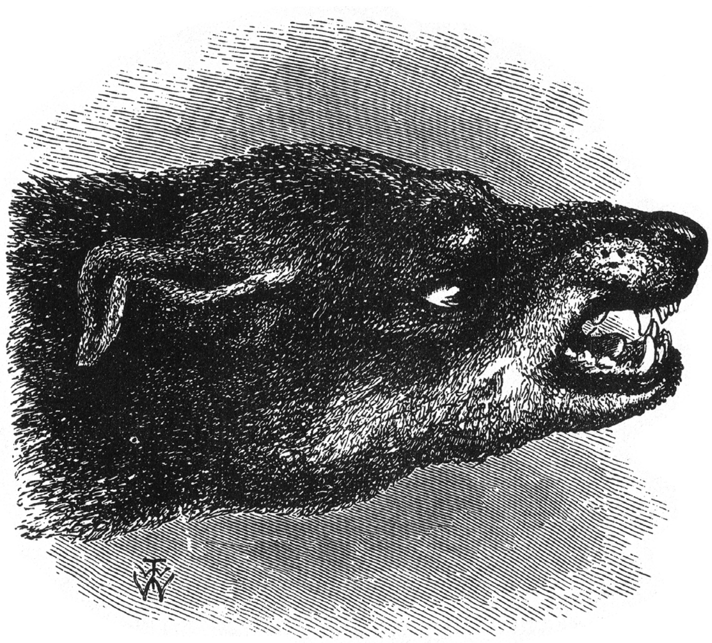


FIG 6.
"Model Mary Bull portrays a sneer" Image from Darwin's *The Expression of the Emotions in Man and Animals*. Source: Wikimedia Commons/ Public domain

> surprise, they are raised to a much greater extent, with the eyes and mouth widely open" [Darwin 1872/2009, p. 257]

Darwin explains these expressions biologically. Regarding the eyes, Darwin attests that we open them widely because we need to perceive more clearly the object of threat or surprise. Regarding the opening of the mouth, he gives various possible explanations. First, he hypothesizes that we open our mouth because it helps us hear better, a hypothesis he then dismisses; he then suggests this opening of the mouth makes us more attentive to sound or helps us breathe more quietly and easily.
To prove the universality and innate nature of emotions, Darwin often draws parallels between expressions in humans and animals. In the chapter describing variances of the bodily actions expressing anger and hatred, he discusses the "uncovering of the canine tooth on the side" as characteristic of the states of mind of sneering and defiance. The lips are retracted and the grinning teeth exposed, and the "upper lip retracted in such a manner that the canine tooth on the one side of the face is shown; the face itself being generally a little upturned and half averted from the person causing offense." [FIG. 6] He then adds that "the action is the same as that of a snarling dog; and a dog when pretending to fight when often draws up the lip on one side alone, namely that facing his antagonist" noting that the our word sneer is the same as snarl, which was originally snar [Darwin, 1872/2009, p.226] [FIG. 5].

Darwin observes that a trace of sneering expression can be found in the sardonic smile; "The lips are then kept joined or almost joined, but one corner of the mouth is retracted on the side towards the derided person; and this drawing back of the corner is part of a true sneer." Due to the similarity to an animal's expression of uncovering the canine tooth, Darwin concludes that our "semi-human progenitors uncovered their canine teeth when prepared for battle, as we still do when feeling ferocious, or when merely sneering at or defying someone, without intention of making a real attack with our teeth" [Darwin, 1872/2009, p.226, 230] [FIG. 5-6].

According to the second principle -- the principle of antithesis -- our bodies and muscles tend to have opposite actions when expressing opposite emotions. For example, Darwin shows how when dogs have hostile intentions, their bodies become tense, their backs point upwards and their gaze is still; their ears and tail point upwards, the hair is erect. When dogs are relaxed and show affection to a human, their spines curl on point inwards, their tails move rhythmically, and their ears point down.

The third principle -- the principle of actions due to the constitution of the Nervous System -- concerns reflex actions of the nervous systems that were not instantiated by a purpose or even serve the body in any good way. For this he gives the example of the trembling of the body, which can be caused by cold, fever, or fearful emotions but also emotions of great joy. Darwin notes that any "strong excitement of the nervous system interrupts the steady flow of nerve-force to the muscles" [Darwin, 1872/2009, p.70].

Darwin's work is very important in bringing forth the importance of the body in the study of emotions, even if somewhat reductive from a psychological perspective since his study is mostly focused on physiological reflexes governed by states of minds dictating action through various nerves. Although clearly in most descriptions the mind keeps the traditional hierarchy over the body – it is the state of mind that produces the physical expression -- Darwin at times makes comments regarding the physicality of emotion as a necessary condition for the existence of the emotion (an observation that as we shall see will be become the central theorem in William James' psychology). Referring to the importance of the body, Darwin notes the following:

> "Most of our emotions are so closely connected with their expression, that they hardly exist if the body remains passive - the nature of the expression depending in chief part on the nature of the actions which have been habitually performed under this particular state of mind. A man, for instance, may know that his life is in the extremest [sic] peril, and may strongly desire to save it, yet may claim as did Louis XVI., when surrounded by a fierce mob, 'Am I afraid? Feel my pulse.' So a man may intensely hate another, but until his bodily frame is affected he cannot be said to be enraged." [Darwin, 1872/2009, p.217]

The postulation that the physical manifestation of the emotion is the emotion, becomes more celebrated than ever in William James' famous, controversial, and highly influential article "What is An Emotion?" written in 1884 [James, 1884/2007]. James acknowledged Darwin's work as well as other studies on anatomy and emotional expression such Sir Charles Bell's Anatomy of Expression, which was also very influential to Darwin's work. While acknowledging their work, he also noted that investigations conducted so far on the physiological aspects of emotions were mostly limited to external expressions of emotions, especially facial expressions. This was partly because many studies on the physiological expression of emotions, like the one of Sir Charles Bell's, used paintings as the source of their analysis. Darwin went a little further, making some mention of inner physiological sensations, but it was James who declared wholeheartedly the importance of the somatic nature of emotions.

William James, in his seminal paper "What Is An Emotion?" focused on the somatic aspects of emotions by arguing, for example, that "not only the heart, but the entire circulatory system, forms a sort of soundingboard, which, every change of our consciousness, however slight, may make reverberate" [James, 1884/2007, loc. 105]. He also remarked how the blood-vessels of the abdomen, the bladder, and the bowels are severely affected in certain emotions, and that the fluctuations of heartbeat and breathing rate are integral to emotions. According to James, the physiological changes are such an integral part of our emotions that if we take an emotion and remove all its physiological sensation, we are left with a "cold and neutral state of intellectual perception" [James, 1884/2007, loc. 135].

What is truly radical in James's theory is that James went beyond the mere appreciation of the body and its sensation to declare the body as the primary actor in emotional processing; the body is the one that acts first, before our brain and consciousness. Although throughout the history of emotions theorists claimed that it was the brain dictating to the body what to feel, James for the first time put the body first, reversing a long-held assumption. According to James, it is not the mind that expresses the emotions as feelings in the body; the bodily change is the emotion. Contrary to the popular belief that the embodied aspects of emotions are the results of cognitive affective evaluation – that, for example, we tremble because we feel afraid -- James famously contested that:

> "We feel sorry because we cry, angry because we strike, afraid because we tremble, and not that we cry, strike, or tremble, because we are sorry, angry, or fearful, as the case may be. Without the bodily states following on the perception, the latter would be purely cognitive in form, pale, colourless, destitute of emotional warmth. We might then see the bear, and judge it best to run, receive the insult and deem it right to strike, but we could not actually feel afraid or angry."[1] [James, 1884/2007, loc.54-69]

An important experiment in the "embodied" history of emotions that followed James's theory is the one supporting the "Two Factor Hypothesis" by Schachter and Singer [1962], who, while providing further

---

1 James' theory (which was named James-Lange theory, because Lange independently developed a theory similar in some aspects) triggered many reactions at his time, many of them negative. The most famous critique was that of Walter Cannon (later named Cannon-Bard theory because of Bard's similar perspective) which was based on the main arguments that similar physiological reactions may correspond to different emotions, and that since our bodily responses are too slow, there must be a cognitive apprehension of the emotion first. In addition, Cannon separated afferent nerves from the sympathetic branch of the Autonomic Nervous Systems, in experiments in cats to show that emotions do not rely on the visceral changes. These results led him to the conclusion that physiological responses of emotions are a separate and not a necessary component for feeling emotions [Friedman, 2010].

ground to James's hypothesis of the primacy of physiological sensations, they demonstrated the importance of cognitive interpretation in "labeling" the felt emotions. In their paper "Cognitive, Social, and Physiological Determinants of Emotional State" Schachter and Singer [1962] describe the procedure of their elaborate, creative, and scientifically significant experiment.

For their experiment, Schachter and Singer created two main experimental conditions, one with subjects receiving an injection of epinephrine (adrenaline), and one with subjects receiving a placebo (saline) injection. The epinephrine causes physiological effects of high arousal such as increased heart rate and shallow breathing. The experimenters' main hypothesis was that if subjects experiencing such physiological symptoms were presented with a "positive" context they would attribute the feelings of arousal to that positive context; likewise, if they were presented with a "negative" context they would attribute the feelings of arousal to that negative context. Based on prior studies and observations, Schachter and Singer argued that if a satisfactory explanation was given to the subjects regarding their physiological sensations -- i.e. if they knew they were receiving epinephrine and were aware of its affects -- the subjects would not look for an emotional interpretation.

The two groups -- one injected with epinephrine and one with placebo -- were further subdivided into two groups. Participants of the first group (joy group) were arranged as part of the experiment to sit in a room with an actor who would be performing a laugh-provoking act - the act being fooling around in the room, and doing silly actions, all scripted in advance.[1] Participants of the second group (anger group) were arranged as part of the experiment to sit in a room with an actor who would be performing an anger provoking act - the act being acting angry himself and irritated with the questionnaire given to the participants which were purposefully made intrusive and insulting.[2]

---

1 For example in the first act the "Stooge [the actor] reaches for a piece of paper and starts doodling while saying, "They said we could use this for scratch, didn't they?" He doodles a fish for some 30 seconds, then says: "This scrap paper isn't even much good for doodling" and crumples paper and attempts to throw it into the wastebasket in the far corner of the room. The doodling continues on, prompting the experimental subject to participate Schachter and Singer [1962].

2 The questionnaire included questions such as "With how many men (other than your father) has your mother had extramarital relationships?" Or a long series of items such as "Does not bathe or wash regularly," "Seems to need psychiatric care," etc. that request the respondent to write down for which member of his immediate family each item seems most applicable. Questions

In the two groups of Joy and Anger, the experimenters had arranged three conditions (the third acting as a control and being only in the Joy group), and a placebo condition: (1) a condition where the participant is informed about the side effects of epinephrine, (2) a condition where the participant is not informed about any side effects, and (3) a condition where the participant is misinformed about the side effects. None of the participants were informed about the true nature of the experiment. Consistent with the researchers' expectations, subjects were more susceptible to the actor's mood when they had no explanation regarding their symptoms and felt either angry or happy depending on the actor's act [Schacter and Singer, 1962].

The Schachter and Singer experiment was seminal in the history of psychology as it demonstrated both the importance of bodily sensation in the feeling of an emotion and the contextual parameters in the "labeling" of the emotion. Emotion theories today recognize the importance of both physiological and cognitive components, although they are still debating as to which one comes first -- the cognitive evaluation or the emotion -- and which one is more decisive for the categorization of emotions. The debates and discourse over what an emotion is are complex, but seen under a broader perspective, we can generally distinguish between three current trends in emotion theories: appraisal theories, basic emotion theories, and the theory of constructed emotion. The theory of constructed emotion, which serves an embodied approach from a culturally informed perspective, will be used as the basis for the computational framework developed in this thesis.

Appraisal theories can be considered "traditional," in that they argue that thinking occurs before feeling, but also "non-traditional," in that they favor cultural meaning over evolutionary and biological processes. According to appraisal theories, as formulated by Richard Lazarus and others [Lazarus,1984] a triggering event or stimulus will be followed by a thought that will lead to the experience and physiological response of emotion. Emotions according to these theories are cognitive constructions, based on individuals' subjective evaluation of a situation relative to their own goals and their available resources when dealing with a situation. In that respect, appraisal theories are reminiscent of Aristotle's discourse on emotions in Rhetoric, as emotions were viewed relative to speakers and audience's goals and personal life situations.

At the other end of the spectrum are the basic theories of emotion. Such

---

trigger scripted angry responses from the stooge "I'll be damned if I'll fill out Number 25. 'Does not bathe or wash regularly'—that's a real insult " Schachter and Singer [1962] theories, developed by Tomkins [1962], Ekman [1984; 1992], Plutchik [1980] and others, utilize as a precedent Darwin's evolutionary theory of emotions and aspects of James's theory of emotions. Proponents of the basic emotion theories believe that emotions are universal and instinctual; they have been inherited from our ancestors and serve evolutionary goals. Emotion theorists in this group detect a list of basic emotions that differs from theorist to theorist but often includes the emotions of anger, sadness, joy, fear, disgust, and surprise (which is the original list of basic emotions as defined by Ekman). Basic emotion theorists usually refer to James to ground the automatic, instinctual emotional behavior, but also misattribute to him the belief that each basic emotion has a distinct physiological pattern [Gendron and Barrett, 2009]

Many basic emotion theorists have focused on the identification of specific and distinct neural activation patterns for each of the basic emotions. Although such theories have shed light on evolutionary and physiological processes of emotions, the pursuit of categorical biological identification of emotions often oversimplifies emotional processes and gives only minor consideration to cultural aspects [Barrett, 2017]. The idea that emotions can be grouped in universally identified patterns has been challenged as attempts to find neural or physiological signature for emotions usually yield limited results.

The theory of constructed emotion formulated by Russell [2003] and Barrett [2017] puts emphasis on the fact that emotions are constructed rather than biologically defined. This theory overlaps with appraisal theories, but at the same time praises James's theory for acknowledging a primacy of the bodily, physiological reaction over cognitive evaluation. This theory is thus to a great extent a derivative of the two-factor theory, as it acknowledges both the importance of non-intentional or automatic physiological aspects of emotion and the appraisal component of allowing different "labels" to be attached to the bodily feelings, depending on the situation. Contrary to basic emotions theorists who [wrongly, according Gendron and Barrett, 2009] attribute to James the idea of identifiable emotion patterns, the theory of constructed emotions credits James for acknowledging the complexity of physiological and cognitive processes involved in emotions [Gendron and Barrett, 2009].

The theory of constructed emotion is based on the concept of Core Affect and the Affective Circumplex model developed by Russell [1980] and Barrett [Russell and Barrett, 1999]. Core affect is a basic bodily feeling that we constantly have "in the background" and can be defined in the two dimensions of arousal and valence.[1] Core affect is different from

---

1 Dimensional theories of affect had been proposed before, in various kinds. One of the first ones was proposed by Wilhelm Wundt [1986].

“emotion” in that it is basic, instinctual, and non-cognitive. Core affect is also described as equivalent to “mood,” a usually long-lasting “feeling,” or as a background emotion. In different contexts core affect can be evaluated in different ways, through an appraisal process that takes into account personal goals and judgment and the cause it is attributed to. This appraisal process is “constructed,” as the same feeling can be attributed or misattributed to a different cause depending on the situation.

Russell defines a “prototypical emotional episode,” what in everyday terms is essentially an emotion, as involving several physiological and cognitive components, including the cognitive categorization (labeling) of the emotion based on culturally defined descriptions -- what Russel calls the “folk concepts underlying the words of fear, anger, jealousy, and so on” [Russell, 2003, p.150]. The distinct types of emotions are not completely dismissed in the constructed emotion theory but are defined as species of certain kinds with no identical neural or physiological pattern [Russell, 2003].

As is evident at this point, what an emotion is has been very much debated over the centuries. “Emotion” is a constructed concept that has masked the many nuances of words for feelings that existed before its invention, and that still masks the nuances of the processes involved in what the term means today. At the same time, the discourse on “emotion” relies much more on the body and its physiological process than in ancient and medieval times. Emotion, which was once considered a disturbance of the pure and rational soul -- associated with sin and ill thinking, or at best a reflection of the brain on the body -- is now considered part of both our bodily and cognitive processes.

2.1.2. BODY-MIND CONNECTIONS

As discussed in the previous section it was not until the 19th century that the discourse about emotions started to focus on the functions of the body, the physiological and neural process tied to experiencing an emotion. Although today there is still an ongoing debate regarding the nature of emotions, most prevalent emotion theories acknowledge both innate and constructed aspects in emotion processing but differ as to the emphasis they put on each factor. Although I reviewed theories of emotion from antiquity to today, I primarily focused on the different definitions of emotion and the parts that constitute it; I did not explore theories that include deeper discussions on body-mind connections. This will be my task in this chapter, as it will help to construct a better framework for understanding emotional health and possible embodied interventions.

Antonio Damasio's work contributes significantly to our knowledge regarding body-mind connections, informing us on the role of consciousness in feeling an emotion. In The Feeling of What Happens [Damasio, 2000], Damasio designates emotions such as happiness, sadness, anger, surprise and disgust as primary, instinctual and universal, and others such as embarrassment, jealousy, guilt, or pride as secondary or social emotions. To these two categories, Damasio adds the third category of background emotions, giving as an example well-being or malaise, calm or tension. According to Damasio, all emotions have certain biological processes and characteristics in common, including their biological role in aiding the survival of the organism, and their nature as collections of chemical and neural responses. He argues that even social emotions have biological origins even though they change meanings depending on culture and context.

Background emotions refer to sensations of being "tense" or "edgy," "discouraged" or "enthusiastic," "down" or "cheerful," and are thus similar to the descriptions of the states of the "Core Affect" as defined by Russell and Barrett [1999]. Damasio describes the background emotions as being induced internally from either physiological reactions to prolonged physical states (such as physical labor) or prolonged cognitive states associated with emotions (anticipation of something pleasant). Damasio notes that background emotions, although not as expressive as primary and secondary emotions, often manifest themselves in our body posture [Damasio, 2000].

Damasio does not use the words "feelings" and "emotions" interchangeably; rather he uses the word "emotions" more closely the way James discusses them, as raw bodily physiological changes, and the word "feeling" as experiencing those changes. Feeling does not always relate to emotions, it can simply be the feeling of our internal sensations and organs, the feeling of our breathing and heart rate, the feeling of our gut being contracted, the feeling of pain, and so on. The state of feeling is accompanied by a continuous dynamic (mental) representation of the body. Feeling is the "experience of what your body is doing 'while' thoughts about specific contents roll by." According to Damasio, when those feelings match certain body state representation patterns, then we feel an emotion [Damasio, 1994/2005; 2000].

Background feelings, according to Damasio, are the feeling of life itself, our sense of being. What is interesting regarding these background feelings is that in Damasio's theory they are tied to consciousness. He writes, "if you try for a moment to imagine what it would be like to be without background feelings, you will have no doubt about the notion I am introducing. I submit that without them the very core of your representation of self would be broken" [Damasio, 1994/2005, p.151]. Damasio goes to explain how the dynamic representation of our body states is not always in sync with our bodily reality. This is the case, for example, when people whose limbs have been amputated continue to experience the presence of the absent limb. Damasio explains this condition as a distorted representation of self, which is directly connected to our background feelings. He argues that what we feel in the background is a past representation of our bodies that has stopped being updated.

Damasio emphasizes how the body is continuously monitored and how a continuously updated body representation is necessary for a healthy body-mind connection. He writes that "It is intriguing to wonder what would happen if, all of a sudden [the background feeling] were to disappear; if, when asked how you felt, you found you knew nothing about that background state." [Damasio,1994/2005, p.153] Damasio does indeed give an example of an individual whose body state was totally distorted. The person's body state was more like a negation of its current diseased state. Damasio informs us that the condition is called anosognosia, and the person who suffers from it is stuck in a prior body state and appears unconcerned about their medical condition. When the person is reminded of his condition, he seems to acknowledge it momentarily and reverts back to his previous sense of self soon after.

It might be slightly confusing to encounter all the different terminologies Damasio uses to refer to emotions and feelings and their differences. This confusion arises from the fact that Damasio wishes to understand different levels in the relationship between emotions and consciousness. In the Feeling of What Happens, he defines three stages of processing emotions: (1) a state of emotion, which can be generated non-consciously; (2) a state of feeling, which can be represented non-consciously; and (3) a state of feeling made conscious [Damasio, 2000]. Damasio stresses the fact that emotions do not need to be in our conscious awareness to impact our behavior and decisions. He illustrates this point by narrating an emotion study he conducted on David, an individual with severe defects in learning and memory who could not recognize faces of people he had previously met.

Damasio was intrigued by the fact that David, who could never retain in his mind the faces or behavior of people he had met, nevertheless showed through his behavior a preference for some individuals over others. He conducted an experiment with David to figure out why. Damasio asked three different individuals to interact with David. The first individual would act as the “bad guy”, the second as the “good guy” and the third as the “neutral guy,” showing a more brusque, pleasant, or neutral disposition towards David, respectively. Damasio was excited to find out that although David did not remember any of the interactions, faces, or names, when asked “whom would you go to if you needed help,” and “who do you think is your friend in this group” he would choose “the good guy” over 80 percent of the time [Damasio, 2000].

David’s story demonstrates the power emotions have even if they are not in our conscious awareness. As research on emotions suggests, we may find ourselves feeling anxious or edgy and have no clue why; we may then search for possible causes or events that induce such emotions and decide we are anxious because of an upcoming professional meeting. But maybe the real cause lies elsewhere; maybe we have not slept well, have a hormonal imbalance, indigestion, or maybe the weather is cloudy. Damasio argues that events like these can generate bodily responses altering our body state without producing a sensory pattern or representation in our mind that would make us aware of such an altered state. Whether the result of an internal or external cause, emotion can be induced in an unconscious manner.

It is not of course the first time in history that scientists have discussed the non-conscious aspect of emotion; psychoanalytic theories, starting with Freud and continuing to theories of the present, are based on the principle that our repressed memories and desires inhabit our unconscious mind, causing various pathologies. The difference is that in today’s embodied approaches in neuroscience and psychology, the physical body – as physiological sensations, and the brain -- as physical neuronal connections, are at the center of the discussion. The conception of humans as an “organism” instead of a dualistic mind-body entity brings forth new perspectives on holistic pathological treatment; a perspective well known in eastern traditions of since ancient times.

Damasio revisits the notion of an integrated organism -- a notion previously discussed in the work of Ludwing von Bertalanffy, Kurt Goldstein, and Paul Weis – referring to the body, brain and nervous system as an inseparable ensemble. In this regard, the mind is not linked only to the brain but to the whole organism. One notion linked to the integrated organism approach is that of homeostasis. As explained by Damasio, homeostasis refers to the "coordinated and largely automated physiological reactions required to maintain steady internal states in a living organism. Homeostasis describes the automatic regulation of bodily functions such as temperature, and oxygen concentration. To the functions that play a part in homeostasis, Damasio includes emotions and consciousness, as their mechanisms serve the survival of the organism [Damasio, 2000].

Having as a driver of his research to "prove Descartes wrong" -- to deconstruct the emotion/reason division in western thought -- Damasio formulated his famous "Somatic Marker Hypothesis." The somatic marker hypothesis supports the theory that our body has its own physiological emotion markers that unconsciously (or consciously) affect our rational decisions. This hypothesis is supported by clinical evidence of patients who, due to neurological damage to regions of the brain affecting emotions, have lost their ability to make the right decisions – "right" here meaning advantageous to themselves -- whereas their ability to think rationally in logical problems has remained intact. The findings demonstrate that emotions contribute to decision making and rational thinking [Damasio, 1994/2005].

The somatic marker hypothesis emphasizes the embodied aspect of emotions. "Somatic" in Greek means "related to the body" (soma / σώμα). Damasio argues that when making decisions, somatic markers play a crucial role in our reasoning. When making a decision, we are often faced with dilemmas or alternative choices to choose from. If we were to decide merely logically, we would have to lay out our options one by one, list all pros and cons, project possible outcomes in the future and decide through inferential logic. Damasio argues that this is the most inefficient way of deciding, as we would simply become lost in the variety of possibilities and future outcomes [Damasio, 1994/2005].

Damasio argues that it is our emotional bias over one choice or another that leads us to the right choice and that this bias is expressed through the somatic marker. What the somatic marker does is to offer us a negative or positive bodily cue while scenarios represented by the choices unfold in our minds. A certain choice might give us an uncomfortable feeling in the gut or the chest, thus warning us of a possible negative outcome. Those somatic markers, according to Damasio, can be either innate or learned through association with past experiences. The somatic influence can be conscious or unconscious, influencing our decision mechanisms in subtle, embodied ways. According to Damasio, the roots of this mechanism are evolutionary, as it is through embodied markers that we have made choices advantageous for our survival.

Although our bodies usually help us make the right decisions, this method is not foolproof. Our visceral responses are tied to emotions we feel in the present, have felt in the past, or project in future imagined situations. Sometimes bodily signals are overtly connected to emotions; we feel stressed and feel our guts contract; we feel elated and feel the widening of our chest. But as Damasio would agree, bodily markers are often signs of unconscious emotions. How can we be sure to trust those markers? What if those markers are a residue of some past trauma and our bodily sensing system is faulty?

Research on trauma and emotion pathologies reveals that when the body and the mind loose their healthy connection, our body can speak its own language - a language associated with feelings of the past that are stuck in the subconscious parts of our brains. In cases like that we may need to retrain our bodies to bring them to their "present feelings" or else we would always be trapped in a vicious unhealthy body-mind cycle. Bessel Van Der Kolk, in his seminal contribution to trauma research, The Body Keeps the Score [Van Der Kolk, 2015], explains in detail what happens to our bodies when we experience horrible incidents or chronic abuse, and how the trauma expresses itself in our bodies. It reveals how significantly troubled relationships, near-death experiences, and observations of cruelties at war leave deep scars that can manifest as a distorted sense of self or hypersensitive physical reactions.

To understand the complex functions of emotions, and the interplay between the mind and body in cases of trauma, it is useful to visit Paul McLean's tripartite model of the brain, the triune brain. According to MacLean, the brain presents a hierarchical organization with parts acquired through the process of evolution. In order, the first acquired is the Basal Gaglia, also called the Reptilian brain. The second is the Limbic system, also called Mammalian Brain, which was developed subsequently. The third and last to develop is the Neocortex or Rational brain, where the mechanisms for language occur. Whereas the Rational brain is responsible for managing our actions and goals, the two older brains are responsible for the continuous management of our basic somatic needs [MacLean, 1988].

The reptilian brain is located in the brain stem, where our spinal cord meets the skull. The reptilian brain is responsible for all basic functions, responsible for hunger, thirst, sleep, breathing, eliminating toxins, and sensing pain. Right on top of the reptilian brain is the hypothalamus and the brain stem, which control the energy of the body, the endocrine and immune systems, and ensure the balance of the organism -- the homeostasis. If disturbed, these basic functions, usually taken for granted, throw off the equilibrium of an organism significantly. Anxiety and trauma can lead to such disturbance.

The limbic system, which is located above the reptilian brain, is responsible for functions related to our emotions; it monitors threats and dangers and manages our social challenges. The limbic system takes shape after we are born, based on our experiences in conjunction with our genetic predispositions. The limbic system develops according to the relationship a toddler has with their environment; if the toddler feels loved the limbic system is trained in play and exploration, if the toddler feels unsafe and abandoned the limbic system is trained in fear management. The reptilian brain and the limbic system compose our “emotional brain” which is the center of our nervous system, releasing a variety of hormones resulting in the visceral sensations we feel when we are experiencing an emotion.

It is important to understand the architecture of the brain, in order to understand better how strong emotions can express themselves without our being aware of them or being able to control them rationally. When sensory information is received from the environment through our sensory organs -- our eyes, ears, nose, and so on -- it converges on the thalamus. The information then takes two roads. The first road, which is the longest one, leads to the prefrontal cortex, where rational and conscious thought takes place. The second road, which is the fastest one, skips the rational brain and goes directly to the amygdala, which is located deep in the non-conscious limbic system and looks like two almond-shaped structures. The amygdala is thus in the unconscious part of the brain, and evaluates the significance of the incoming emotions.

If in evaluating the incoming information the amygdala senses danger, it sends a message to the hypothalamus and the brain stem, generating a release of hormones and triggering a full bodily response through the autonomic nervous systems (this includes all the functions of organs that are automatic, like our breathing function, our heart function, our gut function, and so on). Van Der Kolk , uses the metaphor of the “cook” and the “smoke detector” to explain the function of the amygdala relative to the information sent by the hypothalamus. The hypothalamus is the cook, as it “stirs all the input from our perceptions into a fully blended autobiographical soup,” making it an “integrated, coherent experience of ‘this is what is happening to me.’” The amygdala is the “smoke detector” because, as mentioned, when it detects danger, it starts signaling to other brain parts and initiates a full body stress response, including the release of cortisol and adrenaline, increasing heart rate, breathing rate, and blood pressure. In short, the amygdala prepares us for a fight or flight response -- to either fight back or run for survival [Van Der Kolk, 2015].

The fact that the path to the amygdala is shorter than the path to the prefrontal cortex allows us to understand why, when responding to danger, our response feels automatic. It is only after our visceral embodied reaction that our rational brain comes to understand what is going on. People who have experienced trauma or high anxiety states often have false alarms from the amygdala (which responds inputs from other regions). These false alarms can make people startle over minor things and perceive harmless events as threats. Such people can also become hypersensitive to stimuli, being constantly on guard. The role of the Medial Prefrontal Cortex (MPFC) after the stress attack is to bring us back in balance. Thus, the MPFC in Van Der Kolk's schema functions as the "watch tower" that watches out for the smoke and helps one realize the real extent of the danger one thinks one is in [Van Der Kolk, 2015].

In persons with trauma, the whole balance of the system composed of the amygdala and the cortex is thrown off, making it difficult to control emotions. Van Der Kolk comments on brain-imaging results of humans in highly emotional states of intense fear, sadness, and anger that show reduced activity in the MPFC: he explains that this justifies why in sudden stressful situations people cannot cope, overtaken by emotions they lose the ability to think rationally. Van Der Kolk asks, "Is the smoke you smell the sign that your house is on fire and you need to get out fast -- or is it coming from the steak you put over too high a flame? The amygdala doesn't make such judgements" [Van Der Kolk, 2015, p.62]. It is the job of MPFC to look over our feelings, emotions, and thoughts in order to organize and modulate the emotional brain. But when the function of MPFC is inhibited, any false alarm triggers a panic response.

Psychological and behavioral treatments usually focus on insight and understanding. However, the emotional mechanisms reviewed so far demonstrate that in many cases the emotional disturbance we experience stems from deeper unconscious processes that cannot be controlled by rational thinking: the emotions do not even reach this part of the brain. A person's understanding may be accurate and they may be fully aware of the the problem yet unable to change through thinking about it. In such cases, emotion regulation can be better achieved through bodily means. These can be top-down or bottom-up regulation strategies. The top-down way, according to Van Der Kolk, focuses on strengthening the watchtower's power, enhancing the ability of MPFC to monitor one's bodily sensations. This enhanced awareness can be achieved through mindful practices like yoga and meditation. The bottom-up processes suggested by Van Der Kolk are those that involve breathing, movement, or touch.

The autonomic nervous system has two subsystems, the sympathetic nervous systems (SNS), whose name derives from the Greek works "syn" and "pathos" meaning "with emotion" and is the one that is responsible for the arousal of the organism and prepares it for a fight or flight response;

this system sends blood to the muscles, speeding up the heart rate and releasing hormones. The parasympathetic nervous system derives its name from the Greek words “para” and “syn” and “pathos,” which means something like “the system besides the emotions.” The parasympathetic system promotes relaxation, slowing heart rate, and resets breathing.

I have so far discussed connections between our mind and body, focusing on the activities of the brain. It is now important to highlight that the nervous system responsible for our mental health extends beyond the brain. In fact, the nervous system affecting our emotions goes all the way to the gut, which some scientists refer to nowadays as the “second brain” [Gershon, 1999]. In his work, Darwin emphasized the connection of the brain, the heart, and the gut: “Heart, guts, and brain communicate intimately via the ‘pneumogastric’ nerve, the critical nerve involved in the expression and management of emotions in both humans and animals. When the mind is strongly excited, it instantly affects the state of the viscera; so that under excitement there will be much mutual action and reaction between these, the most important organs of the body” [cited in Van Der Kolk, 2015, p. 77]

Today many scientific papers are dedicated to the role of the brain-gut axis, which Darwin referred to as the “pneumogastric” nerve. Research shows that the imbalance of the bacterial composition living in the gut causes dysregulation in certain produced hormones, which in turn affects functions of the brain. Although the connection between the brain and the gut had already been observed from Darwin’s time, researchers focused on the impact of the brain in the gut, rather than the other way round. Now we know that just as the brain affects the gut, so the microbiome of the gut affects the brain [Clapp et al., 2017; Sun et al., 2020]. For example, it is found that more than 90 percent of the serotonin is made in the gut. Serotonin is a key hormone that stabilizes the mood. Modern antidepressants (Selective Serotonin Reuptake Inhibitors SSRIs) operate on this exact hormone, increasing its levels [Yano et al., 2015].

Another important contributor to mental health disease stemming from the gut is the release of cytokine. This protein is produced by the gut in exaggerated systemic response to stressors and causes inflammation of the gut. These proinflammatory proteins are believed to cause the neuroplastic, organizational changes and neurochemical dysfunctions that characterize mental health disorders. In addition, proinflammatory cytokines stimulate the hypothalamus, which stimulates the adenophysis to release hormones that stimulate the adrenal release of cortisol, creating a vicious cycle of stress and dysfunction in the organism. Some research focuses on how to balance the gut microbiota through probiotics so as to find an equilibrium in the produced proteins and hormones, which often prove as effective as prescription medications [Clapp et al., 2017].

2.1.3. BOTTOM-UP REGULATION STRATEGIES

Breathing. Breathing techniques, usually brought from eastern traditions, are becoming popular methods for relaxation in the modern western world [FIG. 7]. These are usually taught in yoga or meditation classes, often in conjunction with a cognitive narrative, as a type of mindful meditation. Traditionally, however, in eastern cultures and particularly in yoga philosophy and practice, breathing techniques have had many purposes and health benefits. These are solely focused on the body and the breath, rather than on a cognitive narrative, and can be complicated to be executed and difficult to learn. The traditional breathing practice in yoga is called Pranayama [Iyengar 1981/2013].

B.K.S Iyengar, one of the important yoga teachers, explains that the name of the Pranayama method derives from the words prana and ayama. Prana is the sanskrit word for breath, respiration, life, vitality, energy, or strength, and connotes the soul rather than the body. Ayama is the word for length, expansion, stretching or restraint. The two words together make Pranayama, the “expansion of life force through control of the breath” [Iyengar, 1966/1993, p.33]. Through Pranayama, one can control the senses (including the emotions) to eventually reach the state of Pratyahara (a state one has control over the senses), which allows the mind to enter the state of concentration (Dhyana).

Breathing control in Pranayama consists of three main functions (1) Inhalation or inspiration, which is called puraka, (2) exhalation or expiration, which is called rechaka, and (3) retention or holding of the breath, which is called kumbhaka. The term kumbhaka derives from the Sanskrit word kumbha which means “pitcher, water pot, jar or chalice.” Just as the kumbha can be filled with water or be empty, so the lungs can be filled in with air or be emptied. There are two states of kumbhaka: the first occurs when breathing is suspended after full inhalation, and the second occurs when breathing is suspended by full exhalation. Pranayama techniques also differ as to whether they use abdominal breathing, diaphragmatic breathing, the left, right or both of the nostrils, or combinations of those [Iyengar 1981/2013; 1966/1977].

Breathing control is integral in yoga philosophy and practice. As Iyengar says: “The yogi’s life is not measured by the number of his days but by the number of his breaths.” Practicing pranayama has multiple benefits. The patterns of breathing strengthen the respiratory system and soothe the nervous system. There are many kinds of pranayama techniques, which Iyengar explains step-by-step in his books. Some regulate the breathing to slow it down and pace the heart rate, while others aim at boosting the energy levels of the body. Better breathing control leads to

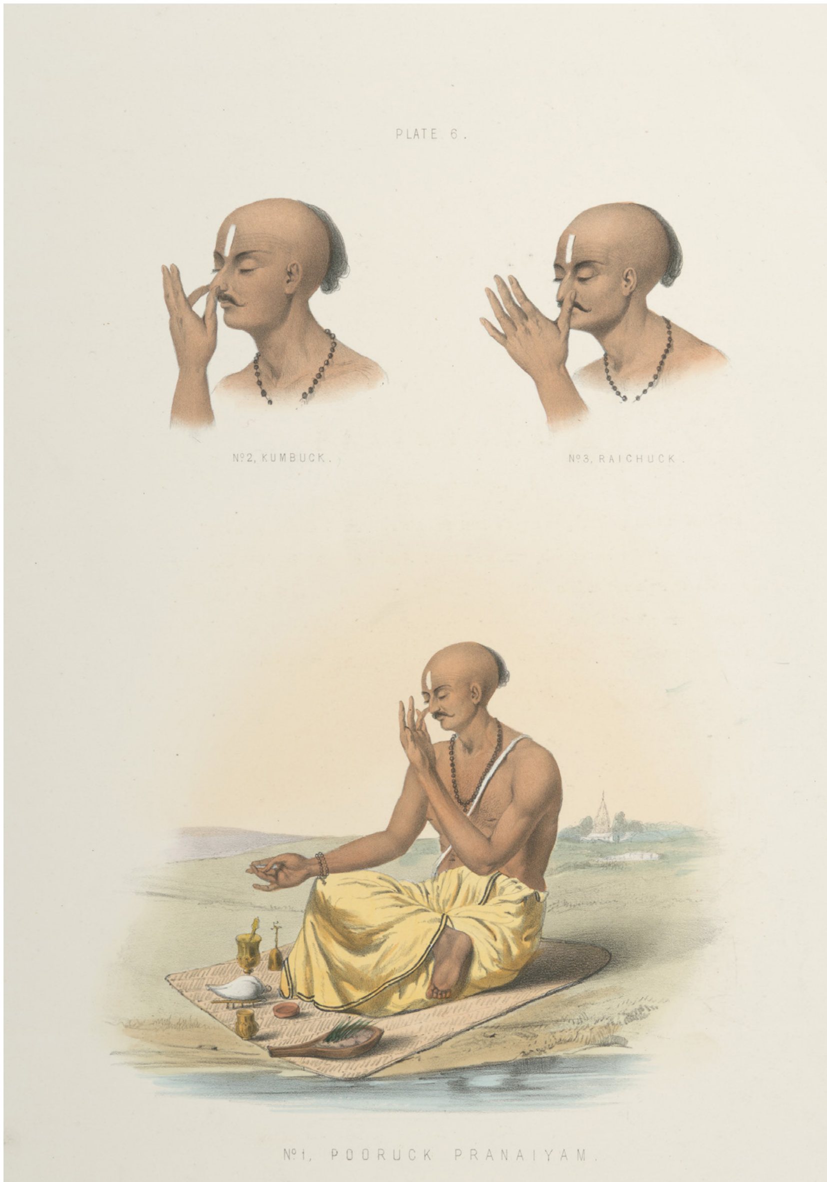


FIG. 7
Centuries of breathing traditions. Drawings portaying pranayama techniques. Original source: *The Sundhya or the Daily Prayers of the Brahmins (1851)* Source: The New York Public Library Digital Collections / Public Domain.

.

better breathing capacity, which in turn leads to better health: It improves circulation, tones the nerves, brain and muscles, increases digestion, vitality, perception and purifies the body and gives access to the “Self” [Iyengar 1981/2013].

Perhaps because of yoga’s popularity, the scientific community has recently focused on studying the effects of regulated breathing on health. Studies on pranayama and similar breathing techniques demonstrate that breathing regulation can activate the parasympathetic system, increase our heart rate variability and promote relaxation. Breathing activity is intrinsically linked to heart activity; when we breathe, our heart rate increases, activating the sympathetic nervous system, and when we exhale our heart rate decreases, activating the parasympathetic nervous system [Pal, 2004; Russo et al, Physiological effects of slow breathing].

Slow deep breathing has been shown to have higher synchronization with our cardiac activity, inhibiting the parasympathetic system and promoting relaxation, whereas shallow and irregular breathing excites the sympathetic nervous system [Jerath et al., 2015]. The phenomenon of synchronization of breathing to cardiac activity is called Respiratory Sinus Arrhythmia (RSA) [Yasuma F, Hayano J, 2004]. During meditation involving breathing regulation, cardiorespiratory synchronization occurs at a ratio of 4:1 or 5:1, meaning that four or five heartbeats correspond to one breath [Wu & Lo, 2010] Studies on slow breathing (<10 bpm) demonstrate that the Heart Rate Variability (HRV) increases, which in turn decreases our Heart Rate (HR) (HRV and HR have an inverse relationship).

Pranayama techniques have also been studied in relation to brain waves, showing increased alpha signal power and decreased theta signal power, indicative of the activation of the parasympathetic system [Zaccaro et al, 2018]. Inhibition of the sympathetic nervous system has been linked to enhanced immune activity in studies on meditation techniques involving breathing regulation. On the other hand, consistent with Iyengar’s warning on novice practitioners [Iyengar, 1981/2013], studies on pranayama have shown that improper breathing regulation practice has been correlated with adverse effects like hyperventilation [Johnson, 2004].

Multiple studies have demonstrated the benefits of regularly practicing pranayama on anxiety [Jerath. Self-regulation of breathing as a primary treatment for anxiety]. Interestingly, a study on the effects of yoga postures and pranayama on anxiety showed that participants experienced a 27% increase in the levels of Gamma Aminobutyric Acid (GABA) levels [Streeter et al., 2007], a neurotransmitter that is the target of many anti-anxiety medications, including benzodiazepines [Griffin, 2013]. Although the calming effects of slow breathing have been well studied, the exact neural mechanisms that cause such effects are unknown. Researchers have formulated hypotheses along two main directions: (1) attributing the effect to the activation to neural activity and tissue changes of the lungs during changes in breathing, and (2) attributing the effects to nerve activity in the nose.

According to the first hypothesis, during inflation the stretch of neural and non-neural tissue in the lungs promotes an autonomic shift, activating the parasympathetic system [Zaccaro et al, 2018]. According to the second hypothesis, nasal breathing modulates the autonomic system and brain activity through nasal receptors sensitive to mechanical and chemical stimuli. Recent studies have demonstrated synchronization between respiratory rate and oscillations in the brain's cortical and subcortical areas shown to depend on the rhythmic air delivery into the nose and not on thoracic respiration [Jerath et al, 2006]. It is important that in both the models and the functions they examine, synchronization between activity neural, cardiovascular activity and breathing patterns is a key component. The more in sync the different bodily functions are, the more activated the parasympathetic system is, promoting a relaxed state.

Touch. From our early development, the sense of touch plays a significant role in our emotion regulation. Touch is involved in shaping our social interactions and controlling the release of important hormones for the balance of our mental health. Touch is the most basic sense, as it is the first to develop in a human fetus, one that even the simplest single-celled organisms have. At the same time, touch is perhaps the most complex in definition of all senses, as the skin is responsible for more than one feeling, and not all of these feelings are considered as part of the sense of touch - cutaneous pain (related to the skin), for example. Even considering the sense of touch alone, leaving aside pain, there are different sensations to consider, like thermal sensation, pressure, and vibration.

From what we have discussed so far about touch, we understand that touch differs from the other senses in that it has multiple "sense objects."' Contrary to vision and hearing that have specific "sense objects" – that is, color and sound respectively -- touch has at least two. In De Anima, Aristotle [trans. 1986], who regarded touch as the most basic sense, contrasted touch with the other senses, noting that touch lacked a single "proper sensible" -- what was termed earlier as "sense object." In Aristotle's philosophy, the "proper sensibles,'' which were each specific to a particular modality, were contrasted with the "common sensibles" that could be perceived from more than one senses, for example, "shape" is a "common sensible" to both vision and touch [Aristotle, trans. 1986].

Regarding the definition of touch, it is interesting that at the physiological level, the nerve channels carrying information about thermal properties are more similar to those carrying information for pain and itch than those carrying information for pressure shape and vibration [Lumpin and Caterina, 2007] Nevertheless, the two sensations that are usually bundled together are the thermal and pressure sensations, whereas pain is usually not considered part of touch [Stanford encyclopedia, touch]. In addition, when considering active touch, which includes some movement (as opposed to passive touch), many receptors are located in muscles, joints and tendons rather than on the skin. Thus touch also involves the engagement of kinesthesis and proprioception, making even more difficult to define the sensory organs of touch. [Gibson, observations on active touch; Loomis and Lederman 1986]

The fact that the sense of touch relies on organs other than the skin and various different nerve functions has created a tendency in cognitive science to treat touch as a multisensory modality [Loomis and Lederman 1986; Fulkerson 2011; Gallace and Spence 2014]. In our discussion concerning the body and emotion regulation strategies, reviewing the diverse nature of touch is important as it demonstrates the different ways that touch can contribute to our emotional balance: through the thermal and tactile sensations of skin, but also through movement and awareness of our internal bodily functions.

The importance of touch in our healthy development and emotion regulation can be observed in many species. Many animals exhibit grooming behavior such as licking and brushing, which help to maintain good hygiene of newborns, and also reduce the newborn's heart rate, as is shown in studies with squirrels, horses, and rats [Feh, 1993, Ferron, 1976; Weaver, 2004]. One study on rats showed that rat pups that were more attentively nurtured during the first week of life grew up to be calm, while those that were not given much attention became anxious, and were more prone to disease [Weaver et al. 2004]. Another study showed that rat pups who were handled more by their mothers had higher levels of antibodies after immunization showing a link between the immune system and touch [Levine, 1962].

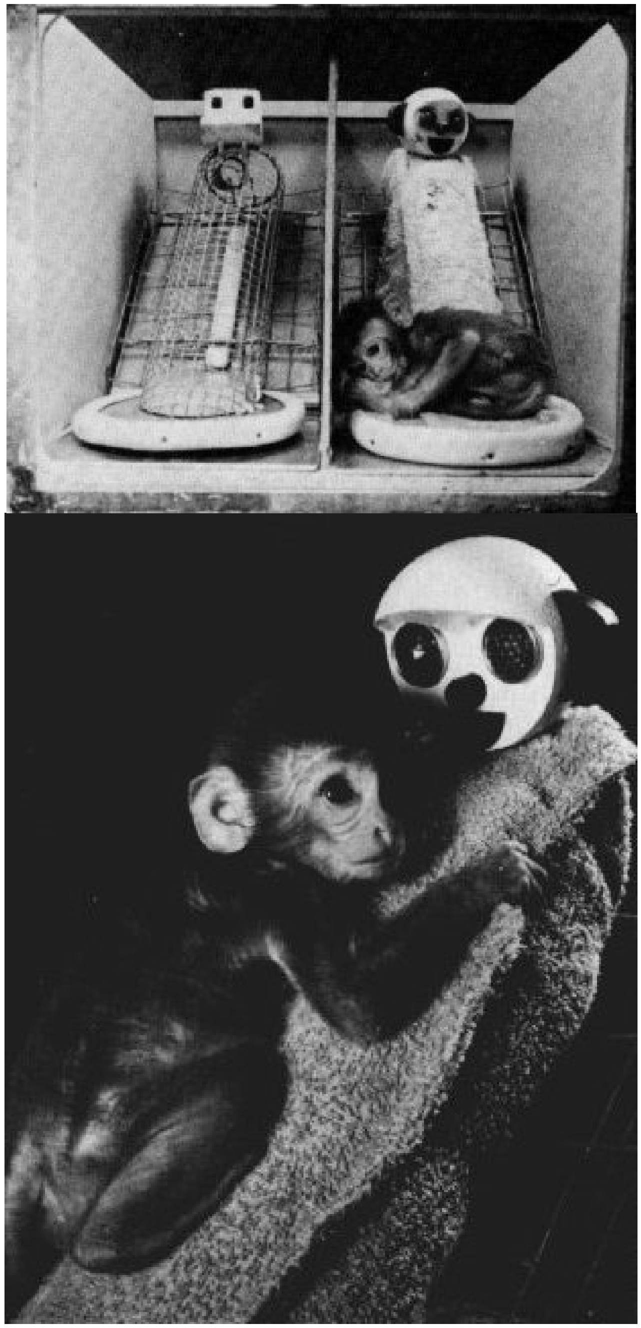
Perhaps the most indicative studies on the importance of touch in early development are the studies with monkeys done in the 1950's by Harlow [Harlow, 1958; Harlow and Zimmermann, 1958] [FIG. 8]. In the study by Harlow and Zimmermann [1958], the researchers used two surrogate monkey mothers: one was made of woven cloth and the other was made of wire mesh. The study was designed with two groups of monkeys: in one group the woven cloth mother provided milk but the wire mesh mother did not; in the second group the wire mesh mother provided milk but the cloth mother did not. The study created a challenge for the young infant monkeys of the second group: would they prefer the metallic mother providing milk or the fluffy mother that left them hungry?

Surprisingly, the monkeys preferred the fluffy mother even when she was not providing milk. Most infant monkeys in the group where the milk-providing mother was made of the wire mesh would sit with the fluffy mother and go to the metal mother only to drink milk. A later experiment with monkeys had the infant monkeys separated from the mother with plexiglass. Although the monkeys could see, hear, and smell their mother they could not touch her. The study showed that deprivation of touch interaction between the infant monkeys and their mother had a negative impact on the infant monkeys' immune system [Suomi, S.J., 1995]

The significant impact of touch on emotional and physical development has also been studied in humans. Studies have shown that a fetus can perceive vibration and can respond to the massaging of her mother's feet [Field, 2014]. Touch is the most dominant sense at these early stages of development as the fetus receives stimulations through the amniotic fluid, and indirectly from her mother through her touch. Studies also show that the tactile interaction between the mother and the child, including skin to skin contact and the infant's suckling behavior, stimulates the release

FIG. 8
A monkey preferring the “surrogare mother” made from cloth from the surrogate mother made from wire mesh providing milk. Top: view of the two “surrogate mothers.” Bottom: Close-up of the monkey hugging the cloth mother. From the study of Harlow and Zimmermann [1958] Original Source: Harlow [1958]. Source: Wikipedia / Public Domain

.



of maternal oxytocin, which influences the physiology of both the infant and the mother, reducing stress, and promoting relaxation and bonding [Uvnäs-Moberg K, 1996; Moberg KU et al., 2020].

Interactions through touch between a mother and a newborn extend to the whole body as the infant can regulate its biorhythms through synchronization with their mother's breathing and heart activity. Studies on maternal separation since the 1970's, including interactions between rats, demonstrated that separation from the mother after birth leads to increased excitability because of the disconnection to the maternal bodily rhythms [Hofer, M.A., 1978]. Recent studies on the bodily interaction between human infants and their mothers confirm the synchronization of their biological rhythms – for example, in their heart rates, which increased significantly during episodes of affect and vocal synchrony. Thus attachment patterns between infant and parent impact the infant's physiological processes [Feldman R, et al., 2011]

Studies on the importance of touch extend to adult relationships. Studies among married couples show that touch can have a beneficial impact on our stress-responsive systems on multiple levels, increasing oxytocin, and reducing blood systolic blood pressure [Holt-Lunstad, J. et al., 2008]. Other studies show that social tactile interaction as in "holding hands" contributes to better adaptive processing of emotional pain [Sahi RS, et al., 2021]. Like mother-infant interactions, tactile interaction between partners increases their physiological synchrony, which is hypothesized to increase bonding and empathy between them [Chatel-Goldman, J., et al., 2014]. Other studies show that increased touch between partners enhances intimacy and wellbeing [Debrot, A., et al., 2013].

Touch has also significant benefits when used therapeutically. Since the ancient times, humans have benefited from manual pressure treatments such as acupressure and massage. Studies demonstrate the benefits of acupressure and acupuncture for reducing anxiety and depression [Smith CA., et al., 2018; Kober A., et al, 2003] acupressure for reducing the symptoms of chronic kidney disease [Kim KH., et al., 2016], and acupressure for treating insomnia [Wu, D. J.,et al., 2018], among other conditions. The benefits of massage have also been well studied for both physical health [Furlan, A. D., et al, 2015; Ferrell-Torry, A., 1993;] and mental health [Garner B, et al., 2008; Ferrell-Torry, A., 1993]

Regarding the neural mechanisms behind therapeutic haptic interventions for mental health, studies have shown that massage can increase levels of dopamine and serotonin, which, in low levels are linked to depression and to anxiety disorders [Field, T., et al., 2005; Hou, W. H., et al., 2010; Berger, G.E., et al., 2008]. A similar impact on serotonin and cortisol levels has also been observed in studies focusing on acupuncture treatments [Pirnia, B. et al., 2019; Lee, E., J., 2016]. The benefits of massage therapy are also measured by an increase in somatic awareness of the individuals. As will we discuss in the next section, many emotional disorders are characterized by limited awareness of one's physical body and detachment of emotions as physical sensations. Massage can contribute to gaining back this bodily awareness [Van der Kohk; Andres, K., et al., 1993; Hedlund, L., et al., 2010].

2.1.4. INTEROCEPTIVE AWARENESS

The connections between our body and mind are crucial for our emotional balance. The sense of touch impacts the connections between our physical and mental self, as it not only helps us perceive our immediate environment and location of our body in space but also contributes to the feelings of our inner self (both physical and mental). In addition, our mental attention to the body's actions, along with controlled breathing, allow us to gain a better awareness of our body's internal functions. This ability, which we can partly ascribe to touch, mental discipline, and autonomic control, is often referred to in scientific studies as interoceptive awareness [Critchley and Garfinkel, 2017; Graig, 2002; Plans et al, 2021].

Studies show that individuals who have had traumatic experiences can lose their bodily awareness. Such individuals may become emotionally numb in an unconscious effort to protect themselves from "reliving" the horror they felt during the traumatic event. MRI studies indeed show a limited activation of brain areas responsible for self-sensing processes in patients with Post Traumatic Stress Disorder (PTSD) compared to individuals without such conditions [Van Der Kolk, 2015]. The decreased self-sensing processing relating to one's own bodily sensations and location in space might be the imprint of the disconnection of these individuals from their emotions; following James' theory of emotions, if we cannot feel the emotions in your bodies, we do not feel them all. When people lose the connection to their body, the path to emotional healing becomes more difficult. Embodied therapeutic processes such as yoga and meditation can put people back in touch with their senses and feelings by enhancing their interoceptive awareness.

Interoception describes the signaling, processing, neural and mental representation of our internal bodily signals [Critchley and Garfinkel, 2017]. In the past, interoception was particularly tied to the viscera; Charles Sherrington, an English neurophysiologist conducting research in the late 19th and early 20th century, categorized the different senses in five modalities: teleroceptive (vision and hearing), proprioceptive (limb position), exteroceptive (touch), chemoreceptive (smell and taste), and interoceptive (viscera). However, recent research findings suggest that interoception is the sense of the physiological condition of the entire body [Graig, 2002].

Recent functional anatomical work demonstrates the existence of an afferent neural system in primates and humans that conveys signals that represent the physiological status of all tissues of the body. The system projects to autonomic and homeostatic centers in the spinal cord and brainstem, complementing the efferent autonomic nervous system. It also generates a direct thalamocortical representation of the state of the body, significant for somatic feelings. This interoceptive system includes the sensations of pain, temperature, itch, sensual touch, muscular and visceral sensations, vasomotor activity, hunger, thirst, and dyspnea (also known as air hunger), and is considered as distinct from the exteroceptive system that includes cutaneous mechanoreception and proprioception [Graig, 2003].

Functional imaging studies in humans indicate a higher level of representation of one's interoceptive activity in creating a meta-representation of the status of the body. This meta-representation takes place in the anterior insular cortex of the right hemisphere and is foundational to the evaluation of one's subjective condition: "the subjective image of the material self as a feeling (sentient) entity, that is, emotional awareness" [Graig, 2003]. Interestingly, the broader meaning attached to the term interoception aligns with earlier theories suggesting the existence of a "common sense" tied to general bodily feelings, as distinct from the five senses. This sensation was termed Gemeingefühl by German physiologists and was also tied to what Sherrington conceptualized as the "material me," which gives one the sense of one's physical self [Graig, 2002].

Interoceptive awareness can be defined as the state in which individuals have access to their somatic condition [Kanbara and Fugunaga, 2016]. Interoceptive awareness can be measured in laboratory settings using the heartbeat perception task, requiring participants to count the number of beats of their heart during a given task, and comparing the subjective count to the actual heart rate. It must be noted that the heartbeat perception task has been discussed in the literature as being a problematic method due to biases in one's perception [Brener, J. and Ring, C., 2016]. Plans et al., [2021] proposed and tested a new method for measuring interoceptive awareness that allows participants at real-time to adjust the phase of tones produced by the phone to the perceived phase of their heart-rate using a dial and a PPG camera-driven sensor.

To develop a refined framework around interoception, Garfinkel et al., [2015] proposed the distinction between interoceptive accuracy, interoceptive awareness, and interoceptive sensibility. Interoceptive accuracy addresses the precision with which subjects detect internal signals; interoceptive awareness refers to the accuracy with which subjects assess their own precision, and interoceptive sensibility refers to the extent to which they attend to their bodily states using self-reports.

Interoceptive (or somatic awareness) is highly related to emotional awareness. Whereas Interoceptive/somatic awareness can be defined as the state in which individuals have access to their somatic condition, emotional awareness can be defined as the state in which individuals have access to their emotional condition. Research demonstrates that alexithymia, a term related to the condition of lacking emotional awareness is related to alexisomia, a term related to the condition of lacking somatic/interoceptive awareness. Alexithymia is a trait characterized by difficulty in identifying and describing feelings. It has been demonstrated that alexithymia is involved in the generation of somatic symptoms or disorders, including gastrointestinal disorders and chronic pain, and medically unexplained symptoms [Kanbara and Fugunaga, 2016]. Alexithymia has also been associated with reduced Theory of Mind (ToM) — the ability to represent the mental states of oneself and others — and inaccurate ToM when the perception tasks rely on emotion cues [Pisani et al., 2021]

Greater levels of emotional awareness are associated with greater levels of emotional differentiation. According to Lane [2006; 2008], greater levels of emotional awareness give access to verbal expression of emotions, whereas low levels of emotional awareness can lead to psychophysiological dysfunctions. Based on Lane's model, emotional processes can be distinguished between explicit and implicit. Whereas explicit negative emotional processes can lead to expression of mental health diseases such as anxiety and depression, implicit emotional processes can lead to interruption of emotional expression, which in turn leads to psychosomatic disorders [Lane 2006; 2008].

Using the heartbeat perception task Pollatos et al., [2007] demonstrated that participants with high interoceptive awareness responded with greater heart rate changes (greater deceleration) to both pleasant and unpleasant stimuli, and that they rated pleasant and unpleasant stimuli as significantly more arousing. For the study, the researchers presented the participants of pictures with affective content. The results indicated that higher levels of emotional awareness are positively correlated to the degree of self-reported arousal. Aligned with these findings, using the method of heartbeat perception task, research demonstrates that alexithymic individuals have less interoceptive awareness. Studies with EEG recordings also demonstrate that interoception has a positive correlation with emotion processing (Kanbara and Fugunaga, 2016).

Interoception is being discussed as a regulatory, homeostatic mechanism, which, once disturbed, can lead to psychophysical dysfunctions. Given the association between somatic and emotional awareness, it is therefore expected that dysregulation of one of the two mechanisms may be associated with dysregulations of the other, along with dysfunctions of the autonomic nervous system. Some studies indicate a hyperaroused autonomic system in individuals with alexithymia [Infransca, 1997; Rabavilas, 1987] whereas others indicate a hypoaroused autonomic system in individuals with alexithymia [Wehmer et al., 1995; Linden et al., 1996; Neumann et al., 2004] Kanbara and Fugunaga [2016] attribute some of the differences to the scientific methods of the studies but emphasize that individuals with alexithymia demonstrate increased arousal at baseline measurements but decreased variability in physiological responses.

Several studies have demonstrated that alexithymic individuals present a greater activation in in somatosensory systems, such as greater activation of the pain matrix area of the brain [Moriguchi et al., 2007], as well as hypersensitivity to visceral stimulation [Kano et al., 2007]. These results are consistent with Lane's theory predicting somatic expression of non-linguistically expressed emotions [Lane, 2008]. Heightened physiological responses do not necessary reflect heightened interceptive awareness but might reflect a dysregulated homeostatic system. A dysregulated homeostatic system can lead to out-of-normal-range physiological responses, expressed either as a hypersensitive or a hyposensitive condition. Kanbara and Fugunara refer to the hypersensitive condition as somatosensory amplification. Somatosensory amplification is "a condition in which sensation of a somatic state is higher than the assumed actual state" and is different from "interoceptive awareness that detects an 'accurate' sensation of a somatic state" [Kanbara and Fugunara, 2016].

The connection between interoceptive awareness and emotional awareness also becomes evident through studies on individuals with depersonalization-derealization disorder (DD). Depersonalization-derealization disorder is characterized by the inability to experience emotions, along with the feelings of detachment from one's body and one's surroundings. Studies including self-report questionnaires and brain imaging demonstrate a decreased activity in neural regions for emotion processing, such as the anterior insular cortex (AIC), the amygdala, the hippocampus, the superior temporal gyrus, and the anterior cingulate cortex (ACC), showing a deficit in subjective emotional feelings. Interestingly, the ability of expression in the patients with DD has been evaluated as "adequate." This discrepancy is being attributed to the inability of emotions to gain conscious representation, which allows emotional awareness [Sedeno et al., 2014].

JM, a patient suffering from DD, described his symptoms as follows: "I feel as though I'm not alive, as though my body is an empty, lifeless shell [...] I seem to be walking in a world I recognize but don't feel" [Sedeno et al., 2014]. JM also felt that sometime his body was floating or levitating, that his hands were changing size, and that his voice sounded distant and unfamiliar. Depersonalization and derealization appears in 0.95% to 2.4% of the population and can also be a comorbid disorder with patients with depression or anxiety or other mental health conditions. DD patients also demonstrate decreased empathic abilities and lack intuitive social understanding (Sedeno et al., 2014).

Sedeno et al. [2014] conducted a study on JM to investigate the connection of the disorder to disrupted interoceptive awareness. In most of the interoceptive conditions measured with the heartbeat perception task, JM demonstrated significantly lowered interoceptive awareness than the control group (significant lower accuracy in the subjective estimation of his heart rate). JM, also scored significantly lower on empathy measurement tests consisting of perspective-taking tasks, empathic concern, and empathy for the pain of others. FMRI comparisons between JM and the control group also provided evidence in support of his emotional impairment and impairment in cognitively processing his bodily signals [Sedeno et al., 2014].

Regarding anxiety conditions, research has shown that a discrepancy between the subjective estimation of physiological signals and actual physiological signals can lead to increased symptoms of the condition. In a study by Story and Craske [2008], participants with anxiety disorder and a history of panic attacks were subjected to a heartbeat detection testing condition that provided either accurate or false feedback regarding their heart rate. Whereas accurate heart-rate feedback elicited only minimal psychophysiological symptoms of anxiety, false heart-rate feedback elicited significant anxiety symptoms, larger heart-rate responses, panic attacks, and self-reported anxiety. The results of this study align with the general framework reviewed, suggesting that better interoceptive processing is associated with better emotion regulation. The results also suggest a heightened physiological reactivity in patients with panic disorders.

Interestingly, anxiety and panic disorders have been correlated in a couple of studies with heightened interoceptive awareness. These include studies using the heartbeat perception task, and studies measuring cardiovascular reactivity to stressors [Pollatos, 2007]. Conversely, regarding depression disorders, most results in scientific research support a negative correlation between the degree of interoceptive awareness and depression symptoms, indicating that lower levels of interoceptive awareness are linked to higher levels of depression [Dunn et al., 2010; Pollatos et al., 2009].

Is a higher degree of interoceptive awareness always associated with better mental health? It appears that individuals with conditions associated with hypoarousal, emotional flatness, or difficulty in emotional expression would benefit from rendering their interoceptive awareness more acute, as this would heighten their emotional experience and awareness, contributing to the treatment of the mental health condition or alleviating some of its symptoms. On the other hand, it seems that individuals with hyperarousal due to hypersensitivity in anxiety conditions might not benefit from rendering their interoceptive awareness more acute, as this might render their symptoms worse – i.e, lead to acute or increased number of panic attacks.

2.1.5. INTERPERSONAL TOUCH, SYNCHRONY, AND EMPATHY

In previous sections, I discussed how the sense of touch extends to our embodied awareness, which in turn extends to our emotional awareness. In fact, following the Jamesian school of thought, embodied awareness and emotional awareness are two sides of the same coin: if we do not feel an emotion in our body, we do not feel it at all. In addition, we discussed how breathing regulation activates the parasympathetic system and that this activation is due to the synchronization of the breath with the heart and neural activity in the brain. In this section, we examine how tactile -- and by extension, embodied awareness -- and synchronization among bodily functions are not only important for the awareness of our own bodily activity and emotions, but also for developing social bonds with others and understanding their emotions.

I discussed in section 2.1.3.2. how tactile communication creates bonding between related individuals -- such as between a parent and a child, or between partners. The impact of touch in positive social relations extends beyond close relationships to social relationships among groups, and even interactions among strangers [Field, 2014]. Certain cultures, however, can be conservative when it comes to touching others as a protective measure against abuse. This non-touching habit, which nevertheless stems from reasonable concerns, can lead to negative social feelings, such as loneliness and isolation. A physician named P.N.K Heylings wrote an article in the early seventies in the British Medical Journal with the title “The No-Touching Epidemic - an English Disease” discussing the feelings of isolation that arise from no-contact cultures, and emotional inhibitions and unusual reactions from inadvertently being touched [Field, 2014].

In an already hostile climate for “touchy-feely” interactions in 2020, and actively occurring while I am writing, the Covid-19 pandemic has forced medically necessary but socially disturbing no-contact measures. Individuals switched to remote work, wearing masks and gloves, isolating themselves in their houses and limiting their interactions to those with individuals from their households. Although the pre-Covid “no-touching epidemic” was embraced by many and criticized by few, during the Covid no-touching pandemic there has been an outburst of writings in the social media, magazines, and scientific journals regarding the negative effects of touch deprivation to our emotional health at both the individual and the social level [Sigley I., 2021].

Alan Fiske, an anthropologist known for his study of human relationships, who developed the Relational Models Theory (RMT), considers body contact between individuals as one of the basic elements that constitute

FIG. 9
Touch and synchonization of the bodies as part of cultural expression and social bonding *Oberon, Titania and Puck with Fairies Dancing,* c.1786. Painting by William Blake. Source: Wikimedia Commons / Public Domain

FIG. 10
Touch and synchonization of the bodies as part of cultural expression and social bonding: *Witches' Flight,* 1797. Painting by Francisco De Goya. Source: Wikimedia Commons / Public Domain

what he terms as Communal Sharing. As Fiske notes, body contact is one of the basic actions involved in forming a community: “hugging, caressing, shaking hands, kissing, nuzzling or touching the other’s body with one’s nose, grooming, sitting in a lap, carrying a baby, holding hands potentially mark and make Communal Sharing (..) So does sleeping alongside (someone).” Touching in the context of social bonding constitutes more than mere communication; it suggests a continuity of a body to another, the extension of the sense of self to include the other as a merged entity, as someone who shares common bodily substance [Fiske, A. P., 2004; Rennung, M., & Göritz, A. S., 2016].

Touching is part of what makes us “same,” as are all basic forms that constitute what Fiske calls Communal Sharing. Fiske argues that this tendency towards sameness is the primary mode of enacting Communal Sharing which he defines as Consubstantial Assimilation: the act of “making of the substances, surfaces, or motions of the body equivalent.” Consubstantial Assimilation exists in many forms: food sharing and drinking together is part of consubstantial assimilation, as is any ritual consisting of taking drugs or other substances. Giving birth and nursing is also part of Consubstantial Assimilation. Fiske notes that changing one’s body to be similar to others’ in certain ways is also part of this bonding process. Changing one’s body may include processes of circumcision, excision, scarification, piercing, tattooing, clothing and other body markers [Fiske, A. P., 2004].

In addition to the previously mentioned practices of touching and sharing, according to Fiske, other practices of Communal Sharing are those of imitation and synchronization: engaging in rituals involving dancing, singing and other bodily synchronized actions [FIG. 9 - 10]. These practices may include religious ceremonies and rituals, political performances, or initiation rites. Contemporary dance practices or rhythmic movements of a crowd in accordance with electronic music are basically part of the same repertoire of Communal Sharing. Whereas imitation and synchronization both involve repetition of the same actions, imitation is usually discussed as having a time lag [Rennung, M., & Göritz, A. S., 2016]. However, even in synchronization there can be a leader and a follower in the action with a brief time lag between them [Mu, Y., et al., 2017].

Imitation and synchronization are regarded by many social psychologists and anthropologists as one of the basic principles in the forming of communities and culture. In the broader aspect of imitation, we tend to follow trends, share political and cultural identities, and belong to groups conformed by rules. In the narrower aspect of synchronous action, Emile Durkheim, a French sociologist who is regarded as one of the fathers of the academic discipline of sociology, studied the rituals of Australian tribes to conclude that synchronization of action produces social solidarity, the sense of unity and community. He argued that collective rites signify the rise of the collective identity and interdependence; rituals transcend self-interest and create social sentiments [Fiske, A. P., 2004].

Coordinated rhythmic movement that can last for hours, as in contemporary electronic music parties, has been studied to have a bonding effect. Studies on rave party participants demonstrate that they feel connected with one another and share a sense of togetherness and openness, even though they may be total strangers with one another. Of course, one could add the effects of the psychoactive drugs many of those participants take, but research shows that the drug effect is not the only factor [Fiske, A. P., 2004]. Military synchronous movement has also been argued to promote prosocial behavior and feelings of bonding. It has been suggested that synchronized rhythmic movements in military drills creates bonding and contributes to success in warfare [Fiske, A. P., 2004]. McNeil [1995], who studies the phenomena of synchronous movements in military drills, claims these movements heighten positive emotions, bind the community together and make cooperative efforts easier.

Although studies observing the connection between synchronized movement and prosocial behavior have existed at least since the early twentieth century in the work of Durkheim, it was not until 1992 that scientists realized the importance of our motor functions in understanding others; this occurred when the role of mirror neurons was discovered [Rizzolatti, G., & Craighero, L., 2004]. A team of Italian scientists discovered mirror neurons in a lucky accident: they had attached electrodes to neurons of a monkey's premotor area to determine which neurons fired when the monkey picked up a peanut or a banana. While the experimenter was putting food in a box, he realized that the monkey's neurons were firing in the location where motor command neurons are located -- only that the monkey was not moving at all, he was remaining still watching the experimenter [Van Der Kolk, B., 2015 ; Rizzolatti, G., & Craighero, L., 2004].

Following the initial discovery of mirror neurons, many studies confirm that we “mirror” others' actions, through activation of our brains motor areas, as part of our process of understanding these actions [Rizzolatti, G., & Craighero, L., 2004]. But even before the more invasive neural studies in monkeys and the brain imaging studies in humans showed evidence of this mirroring, a variety of studies had made arguments regarding our mirroring behavior based on observations of humans actions. These older studies supported the notion that we tend to mirror others' posture or actions and that this tendency for mimicry reflects our understanding and agreement [Hatfield et al., 1994].

In 1964, a psychotherapist named Albert Scheflen argued that mirroring another's posture is a reflection of sharing the same "psychological stance" [Scheflen, 1964]. Subsequent series of studies showed that students tend to mimic an instructor's posture as part of their reflection of understanding, with the interesting observation that more cohesive groups of students would mirror (as in reflection symmetry) rather than mimic the action [La France, 1982; Hatfield et al., 1994]. Other similar series of studies by Bavelas and his team [Bavelas et al, 1988] also described the prosocial behavior and solidarity involved in mimicking others actions. The researchers wrote regarding mimicry: "Specifically, motor mimicry encodes the message, 'I am with you' or 'I am like you,' by displaying a literal mimesis of the other's behavior. By immediately displaying a reaction appropriate to the other's situation (e.g. wincing for the other's pain), the observer conveys, precisely and eloquently, both awareness of and involvement in the other situation" [Bavelas et al, 1988, cited in Hartfield et al., 1994, p.36].

Ferrari and Rizolatti [2014], in a paper revisiting their work on mirror neurons, discuss that there are two prominent philosophical views regarding how we understand others. The first one, following the analytical tradition, posits that our understanding of others' intentions is "based on the observer's capacity to infer others' internal mental states" and ascribe them to a "causal role in generating the observer behavior." The second one, following the phenomenological view, posits that the way we understand others is "by comparing an action done by others with our own behavior in a similar situation." Ferrari and Rizolatti argue that although the discovery of mirror neurons did not disprove the analytical view, it provided concrete evidence in support of the phenomenological view because their work showed that "action understanding through mirror mechanism is a direct activation of motor representation" that "does not require a cognitive simulation of others' behavior" [Ferrari P.F. & Rizzolatti G., 2014].

The mirroring action -- our tendency to mirror in our bodies what happens to others -- is not limited in action understanding. Studies have shown that part of the process of understanding the emotions of others relies on the activation in our brains in similar areas to those of the person experiencing the emotion. One study on the emotion of disgust involved participants inhaling odors producing negative sensations and the same participants observing the facial expressions of disgusted individuals in a video, demonstrating that both conditions activated the same brain areas [Wicker et al., 2003]. Another study placed the focus on intensity of shared emotions of anxiety based on empathetic traits, highlighting the fact that individuals that are highly empathetic are more prone to experiencing vicarious anxiety [Shu, J., et al., 2017].

A third study showed that imitation and observation of emotions activated similar brain areas, although a greater activation was noted during imitation. This study connects action imitation with emotional understanding [Carr L, et al., 2003]. Finally, another study accessed the emotional response of an individual to another closely related individual, when the second person was experiencing pain. Using MRI, the researchers compared the brain activity of volunteers when receiving a painful stimulus themselves with the activity that occurred when their loved ones were receiving it. They concluded that similar areas of the brain are activated, but only the areas responsible for the affective response and not the ones responsible for pain [Singer, T., et al., 2004].

Should we assume the involvement of mirror neurons or similar mechanisms in empathetic processes? It is difficult to provide a direct answer as there has been no direct evidence so far of mirror neurons in the human brains. Despite this limitation, one study on the activation of viscero-motor centers emphasizes mirror neurons as the basis of understanding others and suggests that a similar mechanism is involved in understanding the emotion of others, [Gallese, V., et al., 2004]. However, most of the studies that have been conducted focus on emotions of negative valence and emotions related to the sensation of pain. Studies incorporating emotions of opposite valence have found mixed results. For example, Perry et al [2012] investigated empathy for distress and joy and showed that they led to the activation of similar areas of the brain. On the other hand, Morelli et al. [2014] showed that pain and anxiety activated different areas than were activated in happiness.

To support the hypothesis that emotions are indeed mirrored in the other, in theory each “class” of emotions should activate corresponding different areas of distinct valence [Lamm, C., & Majdandžić, J., 2015]. Of course, given the difficulty -- or impossibility -- of identifying emotions patterns in the brain in the first place, as is argued in the theory of constructed emotions [Barret], the mismatching results in these studies should not be surprising. Perhaps we should not be looking for one-to-one mappings if indeed the same kind of emotions have various neural patterns and expressions but for other types of correlations or similarities.

The study of the phenomenon of interpersonal synchrony and its implications for prosocial behavior and empathy extends in physiological synchrony -- the synchronization of one’s physiological functions such as heart and breathing rate with those of another. As early as the 1950s, a series of studies showed that in the process of psychotherapy, the heart activity of the therapist and the client often synchronized or varied inversely from one another [DiMascio et al., 1955]. Subsequent studies on the same topic showed that the therapist’s and client’s heart rates in generally tend to synchronize -- slowing down or speeding up together

-- depending on the conversation topic and feelings discussed, but they could also increase or decrease in the opposite direction if the therapist and client are in an “antagonist relationship” [DiMascio et al., 1957]

The phenomenon of synchrony in physiological signals between individuals takes different names in the studies, including physiological synchrony [Palumbo et al., 2017], emotional contagion [Hatfield et al., 1994], physiological coregulation, physiological linkage [Timmons, A. C., et al., 2015], and more broadly, interpersonal synchrony. Here we will adopt the term physiological synchrony to refer to the synchronization of biological signals such as heart rate, breathing rate and skin conductance, and we will consider this phenomenon as a subcase of the broader phenomenon of interpersonal synchrony. Interpersonal synchrony has been defined in literature as a state that refers to “instances when movements or sensations of two or more people overlap in time and form” [Rennung and Goritz, 2016]

Interest in physiological synchrony has increased in recent decades, with many studies focusing on physiological interrelation between life partners and married couples. In a seminal paper in this area of investigation, Levenson, R. W., & Gottman, J. M [1983] studied 30 married couples and their physiological synchrony in terms of heart rate, skin conductance, pulse transmission time and somatic activity. The study demonstrated physiological synchrony being stronger among distressed couples, especially in situations of high conflict. Based on the results, researchers hypothesized that dissatisfied couples could not disengage from the conflict; this was expressed in the physiological linkage, contrary to what occurred with satisfied couples who could “step back” from the argument. Other studies have provided evidence of positive physiological synchrony in negative interaction; for example, Reed et al., [2003] showed negative correlation of negative interaction with blood pressure synchrony.

Despite arguments following these studies that non-physiological synchrony might imply healthier reactions in relationships [Levenson, R. W., & Gottman, J. M., 1983], many other studies have shown evidence in support of synchrony in neutral or positive interactions. For example, a study by Helm et al., [2014] demonstrated stronger physiological synchrony in couples with better quality of relationships. In the study, 32 couples participated in conversations tasks involving a topic of agreement, an open discussion, and a topic of disagreement. The results were evaluated based on measurements of respiratory sinus arrhythmia (the heart rate variability in synchrony with respiration). Other studies have shown that physiological synchrony occurs in neutral tasks, as when couples are sitting next to each other. One study showed that heart rate synchrony was developed even when the persons were blindfolded [Ferrer & Helm, 2013]. Another study showed that physiological synchrony occurred when the two individuals from the couple were facing each other but not when they were not [Liu, S., et al., 2016].

Taken together, the results from the studies suggest that emotional understanding involves interpersonal and physiological synchrony. The results of the studies tend to vary based on the context and instructions given to participants. Regarding interactions in healthy relationships, questions are raised in the literature regarding types of synchrony and whether synchrony is always helpful or not in helping manage the emotions of another person [Timmons, A. C., et al., 2015; Hatfield, 1994; Helm, J. L., et al., 2014]. It seems that synchrony can be a reflection of empathy -- whether ‘embodied’ empathy is necessary for helping another or to what extent we need to feel empathy to help another, is a topic I will not discuss further at this point. When investigating the role of synchrony in physiological responses, it is also important to mention the work of Parkinson and their colleagues investing similarities in how we process information based on social proximity [2018]. Utilizing functional magnetic resonance imaging (MRI), Parkinson and their colleagues demonstrated that friends tend to have more similar neural responses to perceived audiovisual cues of naturalistic movies than non-associated individuals..

Connecting the previous discussion on interoceptive awareness with interpersonal emotional understanding - or empathy - it is important to note that studies have shown that higher interoceptive awareness is positively correlated with empathic abilities [Ainley V., et al., 2014; Grynberg and Pollatos, 2015]. In other words, the better we manage to be in synch with ourselves and understand which emotions we feel, the better the chances we have to understand the emotions of others. Research on cognitive empathy indicates that a significant factor in evaluating another’s state is the evaluation of our own subjective state [White, 2016]. Neuroimaging studies demonstrate an overlap in the neural mechanisms involved in interoceptive, emotional, and empathic experiences [Sedeno et al., 2014].

2.2 AESTHETICS OF RESONANCE AND ENACTIVE COMPUTATIONS

2.2.1 EMPATHY AS EINFÜHLUNG

Many of the studies I discussed in the previous section (2.1.5) focused on the impact of movement synchronization or physiological synchronization on empathy. In these studies, empathy referred to understanding the emotions of another individual -- the common meaning of the term. This meaning sometimes assumes that there is an absolute understanding of the other's feelings, a sort of transference from the other person to us: when we empathize with others, we strive to understand and share their feelings, without the others' necessarily having explicitly communicated them to us.

The first definition given by Merriam Webster for the term empathy is:

> Empathy [1]: "the action of understanding, being aware of, being sensitive to, and vicariously experiencing the feelings, thoughts, and experience of another of either the past or present without having the feelings, thoughts, and experience fully communicated in an objectively explicit manner."[1]

The Cambridge Dictionary gives this definition for the term empathy:

> Empathy: "The ability to share someone else's feelings or experiences by imagining what it would be like to be in that person's situation."[2]

In the history of empathy, the term was sometimes followed by moral imperatives, prompting one to understand the other objectively but also in such a manner that does not impede one's ability to help the other manage their emotions. In 1955, Reader's Digest defined empathy in the following manner [Lanzoni, 2018]:

> Empathy: "The ability to appreciate the other person's feelings without yourself becoming so emotionally involved that your judgment is affected."

There was a time, however, when empathy did not have these meanings

---

1 https://www.merriam-webster.com/dictionary/empathy Accessed 09/26/2021

2 https://dictionary.cambridge.org/us/dictionary/english/empathy Accessed 09/26/2021

at all; empathy did not mean understanding another objectively or have moral and social interpersonal implications. Quite the opposite: Empathy, contrary to its current dominant meaning, meant projecting one's feelings into an object. Empathy was a term used in the philosophy of aesthetics and in descriptions of aesthetic experience. It signified the sensory appreciation of an object -- usually a work of art or of nature -- through the projection of our feelings into that object, leading to the fusion of our self with that object [Lanzoni, 2018]. Interestingly, the word still retains its original meaning in its second definition in Merriam Webster:

> Empathy [2]: "the imaginative projection of a subjective state into an object so that the object appears to be infused with it." [1]

It is interesting how the two definitions have almost opposite meanings: the first definition has the meaning of the other person projected onto us; the second definition has the meaning of us being projected into the object. Nonetheless, the two meanings do have something in common: the resonance between two entities, whether these are persons or objects. The reason why examining these two meanings together is important is that the dual interpretation of the term empathy opens possibilities for design and intervention. We can seek to create objects that promote resonance between two individuals or we can seek to create objects that resonate with us, with the goal to elicit an aesthetic experience, to provide health benefits, or both. The implications of empathy's dual interpretation and my research motivations will hopefully become more explicit in the next chapter. For now, let us better grasp the initial meaning of "empathy."

The word "empathy" is relatively new; it was introduced in the English-speaking world by Edward Titchener and James Ward in the early twentieth century as the translation of the German word Einfühlung [Ganczarek, et al., 2018]. Einfühlung was a central concept in German aesthetics and was first used and theoretically developed at the end of the nineteenth century by Robert Vischer [1873] and Theodor Lipps [1903, 1906]. The term Einfühlung literally means "feeling into" and is sometimes given the direct translation of "in-feeling." Einfühlung refers to the projection of oneself into another object, environment, or body, although initially the projection was assumed to be into an object. By feeling into an object, one could "transpose" oneself into that object, or environment, by taking an imaginary perspective. Thus, the concept is historically related to panpsychic ideas [Ganczarek, et al., 2018].

Einfühlung involved not only a mental projection, but actual feelings of the body, including the engagement of breathing and bodily posture.

---

1 https://www.merriam-webster.com/dictionary/empathy Accessed 09/26/2021

Although the term was popular in German circles, the use of the term in Anglo-American circles was limited, and today translation of German texts utilizing the term is still limited. However, one proponent of Einfühlung who wrote in the English language, Vernont Lee, helped popularize empathy as Einfühlung through textbooks written in a mainstream tone. In one of her books, entitled The Beautiful: An Introduction to Psychological Aesthetics, Lee writes the following about empathy (Einfühlung):

> “The mountain looks! Surely here is a case of putting the cart before the horse. No; we cannot explain the mountain rising by the mountain looking, for the only looking in the business is our looking at the mountain (...) when we look at the mountain we somehow or other think of the action of rising. (...) we cannot look at the mountain, nor at a tree, a tower or anything of which we similarly say that it rises, without lifting our glance, raising our eye and probably raising our head and neck, all of which raising and lifting unites into a general awareness of something rising. The rising of which we are aware is going on in us.” [Vernon, L., 1913, p. 36]

It is interesting that Lee emphasizes that it is we who become uplifted and rise, while at the same time the action is attributed to the mountain; we project ourself into the object but it is the object’s properties that fuse with us, making us feel a rise in our head and neck. In another section of the book focusing on the “movement of lines,” the embodied aspect of the fusion becomes even stronger through the impact of what Lee defines as “empathic imagination” on the rhythm of our physiological functions:

> “...it becomes intelligible that when empathic imagination (itself varying from individual to individual) happens to be united to a high degree of (also individually very varying) muscular responsiveness, there may be set up reactions, actual or incipient, e.g. alterations of bodily attitude or muscular tension which (unless indeed they withdraw attention from the contemplated object to our own body) will necessarily add to the sum of activity empathically attributed to the contemplated object. There are moreover individuals in whom such "mimetic" accompaniment consists (as is so frequently the case in listening to music) in changes of the bodily balance, the breathing and heart-beats, in which cases additional doses of satisfaction or dissatisfaction result from the participation of bodily functions themselves so provocative of comfort or discomfort” [Vernon, L., 1913, p. 43].

In 1895, Lee and her friend Kit Anstruther-Thomson, who had training as a visual artist began a series of experiments in art galleries to document the effect of art on the body. Using an introspective method, they documented their own personal bodily reactions to works of art. In one experiment, Arthuther-Thomson described her experience observing a chair: as her eyes followed the lines of the chair, her eyes and chest “felt as they were falling apart.” In imitation of the legs of the chair, her feet pressed against the floor. As her eyes scanned the height of the chair, she felt an upward stretch in her body until she suddenly noticed the leaf ornaments on the top [Lanzoni, S., 2018] [FIG. 11].

In the process of perceiving an artwork, Lee and Anstruther-Thomson placed much emphasis on breathing and balance. They believed that aesthetic experience was produced to a great extent through visceral activity, particularly of the heart and lungs. In another of their experiments, Anstruther-Thomson gave the following description regarding her experience of perceiving a jar:

> “The curve outwards of the jar’s two sides is simultaneously followed by an inspiration as the eyes move up to the jar’s widest point. Then expiration begins, and the lungs seem slowly to collapse as the curve inward is followed by the eyes, till the narrow part of the neck being reached, the ocular following of the widened-out top provokes a short inspiration” [Lee and Thomson (1897) p. 548-550 cited in Lanzoni, S., 2018, p. 28] [FIG. 12].

There was thus synchronization between the form and the bodily actions, although that synchronization did not have the one-to-one direct correlation it would have in interpersonal synchrony, when one can, for example, move an arm in response to the other person’s movement of the arm. The synchrony between a human body and the body of a jar is of more subjective nature; it is a product of analogy and imagination because the human body and clay jar are of different kind. Anstruther-Thomson synchronized her breathing and posture with the shape of the jar following the perception of widening and narrowing of its volume. The jar was judged as being harmonious and pleasant because of the effects it had in the body. Lee and Anstruther-Thomson also interestingly argued that forms that were aesthetically pleasing were the ones that served the health of the organism [Lanzoni, S., 2018].

Lee and Anstruther-Thomson also investigated the bodily impact of color, suggesting that one might “inhale color,” a process that “stimulates the eye, nostrils, and the throat and makes things warmer and easier to see,” and that “a landscape adorned with bright squares of color caused a disturbance in respiration, closely linking the eye and the breath” [Lanzoni, S., 2018, p.30]. They also investigated the effects of architectural space on the body. Lee noted in her writings how Gothic arches and columns created a shift in her posture; how being inside a large church created a fusion of self and space; and how movement in space altered one's aesthetic response. Their experiments were published in 1897 in the popular periodical The Contemporary Review.

While Lee and Anstruther-Thomson emphasized the physical sensations of the body resonating with an object, Theodor Lipps, who created the framework for the concept of Einfühlung, emphasized the mental projection into an object. According to Lipps, in Einfühlung the perceivers experience a "mental awareness of striving or effort within the object of contemplation," and at its highest form, they merge with the object [Lanzoni, S., 2018, p.33]. Lipps described the experience of fusing with the object of contemplation -- an acrobat on a tightrope -- as follows: "I am according to my direct (unmediated) awareness in him; I am there high up. I am transported there. Not next to the acrobat, but exactly within him, where he is. This is thus the full meaning of Einfühlung." [Lanzoni, S., 2018, p.33]. Emphasis on fusing with the object of contemplation was also described by Robert Vischer, the other major theorist of Einfühlung, who first made use of the term. According to Vischer, to perceive an object is to "mediate its size with my own," "to stretch and expand, bend and confine myself to it" and to trace the object "from the inside" [Lanzoni, S., 2018, p.32].

Lipps established his theory through a study on 175 illusions, like the Müller-Lyer illusion. What accounts for the illusion is that the subjects perceive the lines as if in movement: they either stretch outward or move inward. The movement felt by the perceiver -- when perceiving lines, or even a Doric column -- constitutes the meaning of the object. He wrote: "I feel myself, generally speaking, in a movement that is perceptively striving after completion. This fact we name Einfühlung. In this constitutes at the same time the aesthetic insight of what is optically perceived." As Lanzoni notes, for Lipps aesthetic pleasure was "our own enjoyment, projected into the object" [Lanzoni, S., 2018, p.32]. The emphasis on the perceiver rather than the object was more clearly emphasized in Lipps' work rather than Lee's; Lee seems to feel the perceived object in a sort of physiological analogy of its form.

There were many proponents of empathy as Einfühlung, especially in the German speaking world, and some conducted experiments to test the validity and specifics of the theory. Psychologist Oswald Külpe, for example, examined the empathic response of subjects while viewing slides of different styles of columns: Doric, Corinthian and Ionic. He noted however that he did not receive the spontaneous Einfühlung responses that he expected, even when he asked the subjects if they felt the sensation of rising while perceiving the columns [Lanzoni, S., 2018]. Other experiments did provide results in support of Einfühlung, as was the case of an experiment conducted in Zurich asking subjects to rely on their bodily sensations to select shapes they found pleasing. In this

FIG. 11
Empathizing with a chair. Original Source: Photographic print accompanying Vernon's unpublished papers on Beauty and Ugliness, VLA, Colby College. Source: Lanzoni, S., 2009. *Practicing psychology in the art gallery: Vernon Lee's aesthetics of empathy. Journal of the history of the behavioral science*s, 45 4, 330-54 .

FIG. 12
Empathizing with a jar. Original Source: Photographic print accompanying Vernon's unpublished papers on Beauty and Ugliness, VLA, Colby College. Source: Lanzoni, S., 2009. *Practicing psychology in the art gallery: Vernon Lee's aesthetics of empathy. Journal of the history of the behavioral science*s, 45 4, 330-54 .

experiment, Lanzoni [2018, p. 39] describes that “one subject scanned a triangle and sensed that it might collapse” and “her chest constrict.” Other “subjects felt they were able to breathe in the presence of certain shapes.”

The study on empathy ranged from perceiving nature to human performance to painting to basic abstract shapes. Perhaps one of the most basic directions in the research of Einfühlung was the research on the affective properties of lines. Columbia University psychologists A.T Poffenger and B.E. Barrows examined the “feeling-tone of lines” by asking subjects to associate lines with various emotions. The researchers were interested in the affective response of lines in different forms of art. The study showed that the most prominent characteristic affecting the affective perception of the lines was the lines’ directionality. For example, slow, descending lines were evaluated as “sad” and “weak” or “lazy”; slow, horizontal lines were evaluated as “quiet” and gentle; Rapid or medium rising angles were evaluated as “agitating”, “furious”, and “powerful” [Poffenberger and Barrows, 1924]

In addition to those of Visher and Lipps, other important theories expressed similar arguments regarding aesthetic appreciation, including that of Heinrich Wölfflin, a Swiss art historian who argued that empathy starts with bodily simulation and ends in mental simulation through one’s experiences of physical spaces and art objects. Wölfflin [1886 p.151, cited in Brinck I., 2018] wrote about architecture, emphasizing embodied sensory-motor aspects in empathic art interactions:

> “Physical forms possess a character only because we ourselves possess a body. If we were purely visual beings, we would always be denied an aesthetic judgment of the physical world. But as human beings with a body that teaches us the nature of gravity, contraction, strength, and so on, we gather the experience that enables us to identify with the conditions of other forms.”

The concept of empathy as the projection of one’s feeling into an object and the fusion between the self and the object of art or nature started to lose its unique ties to aesthetics when it gained the meaning of interpersonal understanding. By 1903, Lipps had already identified different kinds of Einfühlung: a general one for common objects, one for nature, one for the perception of people’s expressions and one for understanding people’s emotions [Lanzoni, 2018, p.37]. Eventually, the primary significance of empathy was replaced by today’s meaning which is the understanding of another’s feelings. Discourse on empathy is now to be found more in textbooks of social psychology rather than aesthetics, and its study often focuses on mimesis and the function of mirror neurons, as reviewed in the previous chapter.

In light of the different notions ascribed to the word “empathy,” some researchers now distinguish between an interpersonal type of empathy and the aesthetic type of empathy, although such distinction did not initially exist [Ganczarek, et al., 2018]. In the discussion of the interpretation of Einfühlung, it is perhaps more interesting to account for other related concepts developed around this term by its main theorists. For example, in addition to defining Einfühlung as “feeling into” an object, Vischer also defined other terms relating to affective responses to objects, like “Zuführung” and “Nachfühlung.” “Zufühlung” means “feeling towards” rather than “feeling into” and is used in reference to the sensory properties of an object. Nachfühlung means “feeling along” an object and is used in reference to motor properties of an object. Considering these different terms, for Vischer, cognitive empathy seems to be distinguished from the motor and sensory empathy [Ganczarek, et al., 2018].

In addition, with regard to an object, Visher also defined different types of sensing, corresponding to the different types of feelings: “sensing into,” “sensing towards,” and “sensing along.” Ganczarek [2018], who addresses this distinction of terms, mentions that for Visher the word feeling had a more primitive meaning than sensing and argues that because of such distinctions, what we term “empathy” today stems more from the idea of mental projection of feelings, than motor and sensory reactions. However, the limited access to German texts on Zufühlung prevents us from having a deeper understanding of the use of the different terms; their distinction and potential overlap.

The early meaning and use of empathy as Einfühlung reveal possible implications for design, as it demonstrates ways that we can resonate not only with another subject but also with another object. Einfühlung suggests that the mechanism for understanding takes place through our bodily reflection and fusion with the other, and by extension, that any interaction with an object has an impact on the perception of our self and the other -- whether a person, tree, or common object. Although the term Einfühlung was eventually abandoned and empathy with objects was displaced by empathy with persons, philosophers and art theorists still address notions of the early Einfühlung, albeit often in different terms. Today, papers in this context often make use of references from embodied cognition [Johnson, 1990; Varela et al., 1991], enactive cognition [Noë, 2006] and extended cognition [Clark, 2010], which emphasize embodied aspects of perception and extension of the mind beyond the physical boundaries of the body.

Vittorio Gallese is one current researcher who connects empathy in aesthetics with interpersonal understanding and scientific discoveries on mirror neurons. Updating Einfühlung with discoveries in neuroscience, he argues that our brains are hardwired to understand both artworks and other people though embodied simulation [Gallese, V., 2001; 2009]. In a similar line of thought, Vezio Ruggieri [1986; 1997; 2001], who initially studied imitations of facial expressions, argues that imitation is the basis for both interpersonal understanding and aesthetic appreciation. Emphasizing the embodied, physiological aspect of empathy, Ruggieri states that perception of human and object forms rely on imitation through muscular tension: observers feel in their bodies sensations as a reflection of understanding the other person or object. He further suggests that there is an optimal level of basic muscular tension that one needs to have for this “imitative decoding” to take place [Ganczarek, et al., 2018].

Following a physiology-based somatic model of empathy, Escrock [2017] uses the term transomatization to refer to phenomena of interaction with an artwork, where some bodily functions of ours become synchronized with some elements of the artwork. He distinguishes transomatization from simulation, as simulation suggests the mimesis of something of the same kind, whereas transomatization suggests the synchrony with something not necessarily of the same kind. Transomatization is highly subjective; it relies on the imagination of the subject, projected on the elements of the artwork. Escrock defines transomatization as a non-imitative form of empathy which “occurs when viewers use a part or process of their own bodies as a non-imitative stand-in, or correlate, for something outside of the self.” As an example of transomatization, he argues that “a viewer’s heartbeat (..) might stand for the effect of a paint dripping onto a canvas. While there are obvious analogies between the beating of a heart and the dripping of paint, the two activities do not directly mirror one another” Escrock [2018].

In a process reminiscent of Vernon's nineteenth century’s self-experimentation studies on Einfühlung, Escrock [2018] uses the painting Morning, Looking East over the Hudson Valley from the Catskill Mountains created by Friedrich E. Church in 1848 to describe his (or rather a hypothetical observer’s) transomatization experiences through the physiological function of breathing. He provides examples of different qualities of breathing that can be effected through the transomatization process: (1) Breathing as Movement: breathing can reflect motor processes such as the observer’s own “imaginative scanning of the clouds over the Hudson”; (2) Breathing as object qualities: the observer’s properties of breath such as lightness, warmth, and moisture could be correlated with the qualities of the clouds affecting in return the function of the breath; (3) Breathing as intensifier: breathing can intensify qualities of the painting, such as the brightness of the sun; (4) Breathing as a vehicle: breathing acts as a means of conveying something, as for example traversing the work more fluidly; and (5) Breathing as a symbol: breathing reflects the time’s cyclical function in the depiction of the morning time [Escrock, 2018].

2.2.2. FUSION IN ACTION

The idea that the observer is immersed in the artwork can be found in aesthetic theories not directly influenced by the concept of Einfühlung but that nevertheless emphasize the active interaction between the observer and the subjective meaning that derives from such interaction. From this perspective, the artwork does not possess a meaning on its own: there is no truth in the creation, or hidden intentions of the creator to be revealed, rather, the observer of the artwork becomes the artist when interpreting the work. Oscar Wilde's "The Critic as an Artist" an essay included in Wilde's book Intentions written in 1891, beautifully reveals this perspective and provides another take on the fusion that can exist between the observer and the object. "The Critic as Artist", takes the form of a dialogue between two friends, Ernest and Gilbert, who in the first part of the dialogue disagree on the importance of criticism in response to art.

In Wilde's dialogue, Gilbert makes the statement that critic's role is equivalent (or higher) to that of an artist; their role differs only in the materials they use to make their art: "the critic occupies the same relation to the work of art that he criticizes as the artist does to the visible world of form and color, or the unseen world of passion and of thought." The critic's work can be worth even more than the artist's work because, according to Gilbert, the critic forms a creation within a creation and is therefore removed from the problem of representation. In fact, as he argues, the highest form of criticism is "the record of one's soul;" the critic sees herself in the work and the work then becomes "a form of autobiography," a reflection of the critic's thoughts [Wilde, 1891/2014, p.23].

Following Gilbert's thoughts, Ernest then asks in response: "The highest Criticism, then, is more creative than creation, and the primary aim of the critic is to see the object as in itself it really is not (emphasis mine); that is your theory, I believe?" And Gilbert replies "Yes, that is my theory. To the critic, the work of art is simply a suggestion for a new work of his own, that need not necessarily bear any obvious resemblance to the thing it criticizes." It is interesting that compared to the descriptions of Einfühlung, in Oscar Wilde's kind of fusion, the object takes the form of the observer rather than the other way round, whereas in Vernon's descriptions of projection into an object, she fuses with the object to become the object herself -- her breathing becomes deeper or shallower in response to a wider or shallower shape of the vase, her posture taller in visual perceptual of column or a mountain. Following Wilde's negation of the art object's meaning, and his statement that the critic is to see the object as in itself it really is not, the object becomes the autobiography of the observer [Wilde, 1891/2014, p.26].

Einfühlung suggests a certain resonance between the observer and the object through the expression of equivalent functions between the two entities, while aesthetic perspectives like Oscar Wilde's suggest the projection of one's own meaning into an entity devoid of meaning. Other perspectives on art and creativity argue for continuous exchange or dialog between the object and the creator that results in the redefinition of the object's meaning in every step of the exchange. Donald Schön [1987] argued that in the design process, the design "talks back" to the designer, who in turn is able to reflect-in-action, "reframing" his perspective. He argues for a "reflection-in-action" process where the practitioner employs a process of improvisation through "trial and error" where "reflection" on each trial and its results sets the stage for the next trial. The process of creating a spontaneous dialog between the object and the creator incorporates the element of surprise; the process is not a premeditated process and can only be explained after the fact. Schön, describes this dialog process in the following words:

> "In the designer's conversation with the materials of his design, (the designer) can never make a move that has only the effects intended for it. His materials are continually talking back to him, causing him to apprehend unexpected problems and potentials. As he appreciates such new and unexpected phenomena, he also evaluates the moves that have created them" [Schön, 1987, loc. 747-749].

A computational approach to the creative dialog between the observer or designer and the object of contemplation or creation is found in Shape Grammar theory and practice, initially formulated by George Stiny and James Gibs [1972] and further elaborated by Stiny [2006], Knight [1994; 2003], and others [Keles et al., 2012]. Shape Grammar is an open-ended rule-based computational process that allows the designer (or observer) to actively engage with and redefine what they see. The designer can define and redefine the design parts on the fly by taking advantage of the embedding relations of shapes. An example Stiny often provides in his lectures is what appear to be two overlapping squares. The identity of shapes in shape grammars is never fixed, as the lines that make up the shapes can be segmented into indefinitely many parts. Thus, you see however many squares you want: one, two, or three; or perhaps you do not see squares at all, but you see L-shapes instead.

Shape grammars allow for natural visual interaction with shapes as happens in the drawing process, as opposed to the interaction allowed by design software, where the identity of shapes is predefined, and no ambiguity is allowed in the process. If operating in a design software, the designer in the case of the two overlapping squares is “forced” to see only two overlapping squares. Contrary to the conventional computational process, in the shape grammar world, you can see anything you like as long as you define a rule to “pick out” the parts you want. The “picking out” happens using replacement rules of the type A → B that the designer can define based on what they see at each point of the process. What is most important is that at each point, the designer can see something different, as new shapes emerge after the application of a rule [Stiny, 2006][1]

Wilde’s concept of the critic as an artist and Stiny’s approach in shape grammars share the perspective that observers can project whatever they “see” onto the object of contemplation. For Wilde it is the act of criticism, the different meanings that emerge through the art; for Stiny it is the act of embedding the shapes that emerge through the drawing. In his paper, “The Critic as Artist: Oscar Wilde’s Prolegomena to Shape Grammars” Stiny [2015] reflects on Oscar Wilde’s work, drawing a parallel with shape grammars: “Wilde inverts Mathew Arnold’s apodictic critical formula to suit himself, so that the primary aim of the critic is to see the object as in itself it really is not (I suppose this is what I’m trying to do for calculating)” and he later elaborates further on the idea, as Wilde suggested, that one impresses in the work his own meanings: “The artist and critic alike are observers, and always for themselves. They see, and what impresses them is in their souls —in the rules they try.”

In a forthcoming book [Stiny, 2018], Stiny uses the schema of seeing (embedding) ---> doing (fusing) ----> seeing (embedding) to illustrate how visual calculation and the application of rules work in regard to the Shape Grammar process. The process of embedding happens at the moment I see shape A in the shape composition. I can then write a rule A ---> B to do something on the composition C by transforming its shape relations accordingly. Once I have applied the rule, the new shape relation will be fused in the composition, which is now transformed to C’ and will allow me to see a new emergent shape, which I can pick up with a new rule, and so on.

The enactive and embodied interaction as part of the creative process, expressed in the Shape Grammar framework is not limited to visual perception. Knight and Stiny have proposed “Making Grammars” [2015] as a framework that goes beyond the realm of shapes to embrace things in all their perceptual dimensions. Making Grammars are an extension of Shape Grammars as they use rule-based replacement operations of the type A ---> B but instead of using just lines, also deal with other “stuff,”

---

1 See Knight [2003a] for a definition and discussion on the concept of emergence

including physical material like strings, colored paint, and so on. These grammars extend beyond visual perception to incorporate other sensory qualities such as acoustic or tactual qualities, as related each time to the computed “stuff.” When “stuff” become finite objects, they turn into “things.” For example, shapes are things made of line stuff; knots are things made of string stuff; paintings are things are made of watercolor stuff [FIG. 13-14].

The framework of Making Grammars builds upon Shape Grammars but also theories of embodied and enactive perception [Noë, 2006] and like-minded related anthropological frameworks focused on the body and the senses [Ingold 2013; Howes, 2005; Malafouris 2004]. Incorporating possibilities of embodied interaction with stuff to make artworks and other things, the improvisational framework of seeing and doing expressed in Shape Grammars is extended in the Making Grammars as sensing and doing. Making Grammars also extends the idea of sensing to incorporate things and tools we use to sense with. Doing can include actions such as “drawing, knotting, folding, typing, throwing, stomping, and so on” and sensing can include “any one or more of our senses, in any of the various ways our senses have been defined” [Knight and Stiny, 2015].

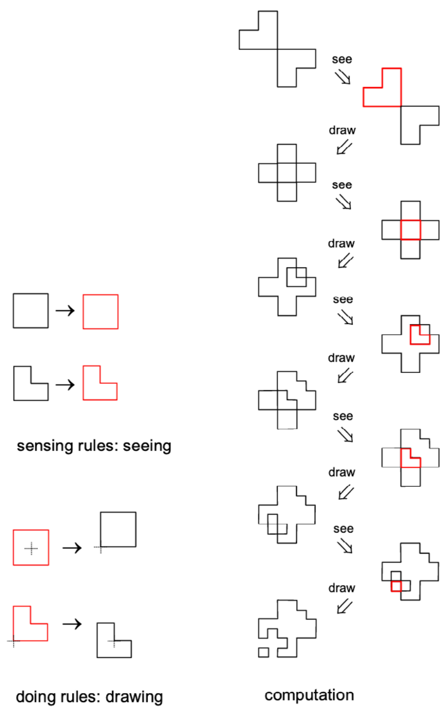


FIG. 13
Making Grammar: Drawing with lines. Source: Knight and Stiny [2015]

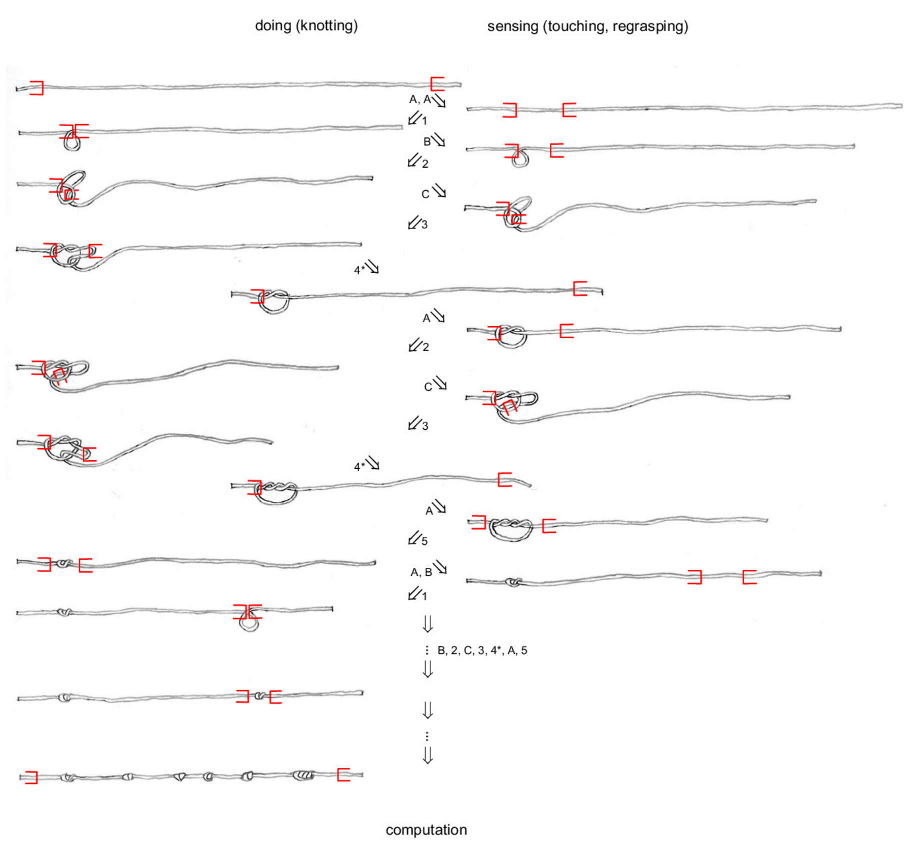


FIG. 14
Computing as sensing (touching, grasping) and doing (knotting). Source: Knight and Stiny [2015]

2.2.3. ENACTION, ENTRAINMENT AND EMBODIMENT

Having reviewed salient concepts from psychology and neuroscience and drawn connections with concepts in aesthetics and design computing, it is useful now to expand on the concept of "embodied perception" to allow us to start building a broader framework around embodied interactions with the environment. Towards this goal, it is important to review theories and concepts around the notion of Enaction, as it is not only relevant to the design computation framework of Shape Grammars and Making Grammars, but also to theories of embodiment in Human Computer Interaction [Dourish, 2004]. Enactive theories are useful in framing embodied interaction with various types of environments, including objects, materials, spaces, and other bodies.

The term Enactive first appeared in the book The Embodied Mind by Varela, Thomson and Rosh [1991] and since then has expanded not only into areas of cognitive science but also into education, design, human computer interaction, robotics, and artificial intelligence. The term has been somewhat generalized and is often used as a synonym for "autonomous," "embodied," "situated," and "dynamical." Any system incorporating the physicality of the body or exchanges of information with the environment can fall under the label of "enactivism," but as Di Paolo et al. [2010] warn, this generalization is a misappropriation of the term, as a system merely incorporating the body or being interactive can still operate in reductive and functionalistic terms.

Reviewing the theories and philosophies contributing to the notion of enactivism, Di Paolo et al. [2010] explain that "overall, enactivism may be construed as a kind of nonreductive, non- functionalist naturalism. It sees the properties of life and mind as being part of a continuum and consequently advocates a scientific program that explores several phases along this dimension." In an enactive perspective "meaning is inseparable from the whole of context-dependent, life-motivated, embodied activity." Among the predecessors of enactivism and contributors to the notion of it, Di Paolo et al. [2010] identify among others, Poincare, Goldstein, Bruner, Heidegger, Dewey, Hutchins, and Damasio, whose theories I discussed earlier. Di Paolo et al. [2010] identify five ideas as being basic for the constitution of the enactive approach: autonomy, sense-making, emergence, embodiment, and experience.

Autonomy: In order for a system to be autonomous or "self-constituent," it must be able to build itself at "some level of identity." In other words, the system's identity should not be fully determined by something external to the system, e.g, from a designer of the system. If a system has no agency in its organization, it is condemned to mechanically follow a predetermined path of operation. The fact that the system is autonomous does not mean it is not constrained. On the contrary, it means that the system is able to set up its own constraints [Di Paolo et al., 2010].

Sense-making: According to the enactive approach, "organisms cast a web of significance" in the world. Their interaction with the environments aims to continue the self-generated identities that regulate this interaction. Organisms engage in transformational processes ("not merely informational" processes) of meaning generation through their bodies and actions: "they enact a world." In other words, sense is not regarded as something static, already existing in the world and waiting to be retrieved; sense is made by the organism through its interaction with the environment [Di Paolo et al., 2010].

Emergence: An enactive system gains its identity through dynamic processes of interaction between an agent and its environment. The meaning does not lie in any specific part of the system but emerges through its function. The concept of emergence describes the formation of novel properties that result from the interaction of processes in a system [Di Paolo et al., 2010]. An early discussion on emergence can be found in the work of John Stuart Mill and George Henry Lewes. Mill observed that individual chemical components do not predict the effects of the components combined [Mill, 1843; see discussion in Knight, 2003a]. The term emergence was later defined by Mill in regard to those effects described by Mill [Lewe's 1875, see discussion in Knight, 2003a].

Embodiment: The enactive approach goes against the Cartesian view of separation between mind and body, where the body is merely seen as implementing the mind's orders. In enactive approaches, the body becomes a "whole animate system with many autonomous layers of self-constitution, self-coordination, and self-organization and varying degrees of openness to the world that create its sense-making activity." According to the enactive approach, cognition is always an embodied process, as it involves our dynamic sensory interaction with the world. Not only are the sensor-motor activities considered to be embodied, but higher cognitive skills are also part of the same enactive sense-making system [Di Paolo et al., 2010].

Experience: In the enactive approach, experience is "intertwined with being alive and immersed in a world of significance." Experience becomes an important tool of knowledge acquisition that is not dependent on information gaining but on the transformation that takes place due to the sense-making that occurs through action. Our bodies-in-interaction and the experience taking place are not two separate phenomena, one dynamic and the other static: along with the transformation of the body and that is happening through experience, the experience is also being transformed [Di Paolo et al., 2010].

The enactive approach can be extended to the study of social interactions. Interaction in is the coupling between one social agent (or system) with another. Two agents can be accidentally correlated or non-accidentally correlated. The non-accidental correlation is also called coordination. When interaction facilitates coordination, the term interactional coordination is used, and when coordination serves a certain function, the term functional coordination is used. An example of functional coordination is given by Moran, Fentress and Golani [1981]:

> “Sometimes wolves when passing one another tend to move in a circle together, head to tail. Through this coordinated behavior the wolves are actually interacting in order to perform a function. The function consists in the wolves’ action of sizing up each other while walking in order to decide whether they should fight or not.”

In interpersonal relations, the enactive approach addresses meaning generation through interaction and relates to the precise timing of functional and interactional coordination processes. This timing of coordination is defined as interaction rhythm and addresses varied aspects of the temporality involved in interpersonal interactions, such as movement, utterances, and posture changes [Di Paolo et al. [2010]. The interaction rhythm refers to temporal organization of elements that span the individuals and elements between the individuals and can have certain degrees of autonomy. Di Paolo et al. [2010] propose the following definition for social interaction, in the context of the enactive approach:

> “Social Interaction is the regulated coupling between at least two autonomous agents, where the regulation concerns aspects of the coupling itself and constitutes an emergent autonomous organization in the domain of relational dynamics, without destroying in the process the autonomy the agents involved (though the latter’s scope can be augmented or reduced)”

A relevant notion to the study of synchronization between agents or regulation within a system is that of Entrainment, which is usually used to describe rhythmic behaviors. Entrainment can be broadly defined as “a phenomenon in which two or more independent rhythmic processes synchronize with each other” [Clayton, et al., 2005]. The phenomenon was identified by the Dutch physicist Christiaan Huygens, who invented the pendulum clock, and since then has been used to describe physical, biological, and social phenomena. In 1657 Huygens noticed that if placed on a common support, two pendulum clocks would synchronize with each other, and if one of the two was disturbed they would eventually regain synchrony. Huygens referred to the phenomenon as the “sympathy of the clocks," "sympathy" being the equivalent word for "empathy" used at the time, as the term "empathy" only came into use in the 19th century. Thus, we might as well call this the "empathy of the clocks"!

Entrainment - at least according to its original meaning - describes the process where two (or more) rhythmic processes interact in such a way that they eventually synchronize in phase and/or periodicity. All processes of entrainment meet two basic parameters [Clayton, et al., 2005]:

> (1)The oscillators (or in general the systems or rhythmic processes) that are in synchronization must be autonomous. This means that when they cease to be in interaction with one another they still exhibit a rhythmic behavior. The rhythmic behavior should not be caused as a result of the interaction, as is the case of resonance: when the window glass oscillates due to the rhythm of a loud music, it is not the result of a process of entertainment because the glass would not oscillate if it were not for the loud music. This is an important distinction with concepts of synchrony (and empathy) reviewed before.
>
> (2)The oscillators must interact. Although many interactions allow for the process of entrainment to occur, it is best that the interaction be "weak" rather than "strong." A strong interaction (coupling) is one that in some ways "ties" the systems together in such a manner that the two oscillators cannot exhibit their rhythmic behavior freely. In other words, the oscillators become too heavily integrated or assimilated in the system and they lose their autonomy.

Entrainment can occur in many forms and circumstances and in different types of systems; it is not limited to mirrored behaviors. Entrainment occurs when fireflies are illuminating in synchrony, when individuals take turns in a conversation and adjust their rhythms of speech, in our circadian rhythms as they adjust to the cycles of daylight, when we tap our feet according to the beat of the song, and so on. Although the outcomes of many entrainment processes can be easily predicted, in dynamic non-linear systems the synchrony results in emergent behaviors that cannot be reduced to the sum of their parts.

Many intrapersonal processes are in entertainment; many human behavior and biological functions are rhythmic, such as our heart and breathing functions, which as discussed earlier, in good health tend to synchronize. This phenomenon - of synchronization between the heart rate and breath, which is called respiratory sinus arrhythmia can be classified as a self-entrainment process, as the entrainment does not involve an external to the body stimulus. Many medical studies have focused on entertainment between different biological rhythmic functions investigating potentials for new treatments. Interestingly, entrainment does not imply stability and stability is not always an indication of good health. For example, stable brain waves may be indicative of epilepsy. Health systems are not rigid and static, they are dynamic and exhibit a certain flexibility, random variation or sometimes even noise [Glass, 1996; Clayton et al., 2005].

In regard to biological organisms, Philips-Silver et al., [2010] propose that the capacity for entrainment requires three “critical building blocks,” which are favored by natural selection and are defined as follows: (1) The ability to detect rhythmic signals; (2) The ability to produce rhythmic signals; (3) the ability to integrate sensory information and motor production which adjusts the motor output in accordance with the rhythmic input. Only when organisms develop such abilities, do they have the capacity for entrainment. Philips-Silver et al., [2010] give the example of the duet courtship dance: The dancers detect the rhythm of the song, then they produce a rhythm by moving their feet accordingly, and then they change rhythm matching their movement to the beat, thus integrating sensory information and motor production. In addition to entrainment with music, entrainment between dancers may also emerge through interactions of visual tactile, and auditory cues.

Dance is a process very characteristic of entrainment, as it relies on the “capacity of at least two individuals to synchronize with instant precision to a shared and steady rhythm, characteristically manifested through whole-body movement.” [Laimera et al., 2019] [FIG.15] The activity of dancing is often described as a cultural phenomenon and, as discussed in the previous chapter (2.1) it is tied to rituals, human bonding and prosocial behavior. It is especially interesting that a recent study on chimpanzees showed that they can also engage in a dance-like, whole-body, non-random synchronized movement process, demonstrating a possible proto-dance in the dance evolution and a possible evolutionary argument for interpersonal psychological benefits. Lameira et al., [2019] demonstrate a ritualized dance-like behavior between two chimpanzees and hypothesize that a similar human proto-dance could be rooted in its social bonding mechanism and stress-release benefits. The researchers describe the interaction of the chimpanzees as follows:

> “The individual initiating synchronous bipedalism, either front or hind, cued the other through gesture or posture. Occasionally they began rocking their upper body while sitting (commonly out of phase) before starting the behavior. By the first or second step individuals were in phase and synchronous. Synchrony was maintained even when walking over large obstacles, such as a fallen log, or when making a turn of 180°.(...) Individuals typically

FIG. 15
Dancing as an entrainment process. *Three Dancers*, c.1888 - c.1893. Painting by Edgar Degas Source: www.wikiart.org / public domain

> collected some object before engaging in the behavior, namely a blanket or bundle of straw. (...). Individuals occasionally paused the behavior and resumed it, taking with them the same objects in the same original direction…"

A useful distinction in the discourse of entrainment is that of symmetrical and asymmetrical entrainment. The entrainment process is symmetrical when both agents of the system (or both coupled systems) influence one another. The process is asymmetrical when only one of the agents of the system (or one of the coupled systems) can influence the other. An example of a symmetric relationship may be that of two jazz musicians improvising and responding to each other while also following an emerging common tempo. An example of an asymmetrical entrainment process is our entrainment to cycles of daylight and dark, which adjusts our circadian rhythms [Wang and Brown 1996; Zeng et al., 1996].

Another useful distinction in regard to the types of entrainment addresses the form of synchronization. Whereas there can be systems that synchronize in both the phase and frequency of the rhythmic behavior, this is not necessary for entertainment to happen. On the contrary, there can be synchronization only in regard to frequency or tempo (frequency entrainment), or synchronization only in regard to phase (phase entrainment). The phenomenon of entrainment is often complex, as the temporal synchrony is not exact: there can be a synchronous behavior followed by anti-synchronous behavior (having opposite values) or there can be a phase difference, in which the temporality of one system is lagging in regard to the other, but still exhibits a constant relationship in their interaction. To capture the complexity of the phenomenon, Bluedorn [2002, quoted in Clayton et al., 2005] gives this definition of entrainment:

> "Entrainment is the process in which the rhythms displayed by two or more phenomena become synchronized, with one of the rhythms often being more powerful or dominant and capturing the rhythm of the other. This does not mean, however, that the rhythmic patterns will coincide or overlap exactly; instead, it means the patterns will maintain a consistent relationship with each other."

Applications of the entrainment concept also extend to social studies. For example, McGrath and Kelly [1986] suggest a social entrainment model that relies on five main propositions: (1) Most human behavior processes are temporal in character; (2) These are endogenous rhythms, inherent in the organisms; (3) Rhythmic patterns within individuals become entrained; (4) Rhythmic patterns between individuals also demonstrate entrainment in both phase and frequency; and (5) Rhythmic patterns within and between individuals become entrained to external temporal events and stimuli. The external events and stimuli alter the periodicity of the intrapersonal and interpersonal synchrony. The intrapersonal and interpersonal temporal patterns alter the onset of the entrainment.

Perception theories around the concept of entrainment offer useful tools that can be applied to music studies. Jones [1976] argues that people have a tendency to entrain to rhythms, such as the beat period in music. This period can act as a reference that locks the listener to the music event and then allows them to selectively shift their focus and attention to different levels of the referent periods. Jones' theories are useful in music studies because they use the concept of entrainment to illustrate the adaptive processes of musical attention and response to musical stimuli, which are partly conscious and intentional and partly directed by the music as external environment stimuli. According to Jones and her colleagues, entrainment is the "synchronous interplay between an attender and an event in which the former comes to partially share the events' rhythmic pattern'" [Jones & Bolz 1989, p.470 quoted in Clayton et al., 2005]

Ethnomusicology studies provide interesting insights around the notion of rhythm that can be extended to entrainment processes in various rhythmic phenomena. Alan Lomax [1982] was one of the earliest ethnomusicologists to address rhythmic coordination and social interaction in his essay "The Cross-cultural Variation of Rhythmic Style." In this essay, he stresses how rhythm connects people, provides a common framework for identification, and facilitates co-activity of groups. Lomax provided interesting findings regarding different metrical patterns in people's movement in different cultures:

> "You can walk in a 1-1-1-1 meter or in a 1-2-1-2 meter, or even in a 1-2-3-1-2-3. The upper body can simply go along with the legs or it can move to an independent meter or in an accompanying pattern. The combinations of the rhythmic patterns in the upper and lower body give rise to more complex meters. For example, Africans produce polyrhythms by moving arms and legs to different meters. One favourite Oriental rhythmic style consists of a steady four in legs (and the percussion section) while the arms follow a free metered melody of a lead instrument" [Lomax, 1982, p. 162, quoted in Clayton et al., 2005].

In this chapter my aim was to expand the notions of empathy and synchrony investigating how they can related to creative design and artistic processes, especially through a computational framework. Through a review of precedents in theories of art and design computing, it became evident that empathy, as an entrainment process of literally resonating with another, is a process not exclusive to relations between humans. Entrainment processes also extend to relations between animals, between humans and artworks, between human and the natural world, and within the natural world. The discussion on definitions of entrainment in conjunction with the discussions on enactivism suggested that enactive systems are defined through a dynamic interaction of their parts that may be rhythmic but not necessarily in absolute synchrony.

2.3. (AFFECTIVE) COMMUNICATION AND SELF-REGULATING SYSTEMS

2.3.1 INFORMATION THEORY AND CYBERNETICS

After discussing theories of emotion and embodied interactions in arts and sciences, it is time to look into models for self-regulation and communication. The models I will review are mainly drawn from postwar theories of cybernetics and information but have influenced today's approaches and extend to current practices. Some of these systems pertain to regulation and communication in broader terms, and some more particularly to emotion self-regulation and emotion communication. These broader models often operate on the analogy of the living organism and are thus relevant to the discourse of embodied computing through this analogy. Finally, I will look into some contemporary approaches and applications of emotion regulation and interpersonal interaction, especially those tied to bottom-up regulation strategies reviewed in chapter 2.1.

The field of Cybernetics emerged from a series of post-WWII meetings during which a group of mathematicians, engineers, and social scientists discussed how wartime theories of communication and control could be applied to humans and machines. The term Cybernetics was adopted in 1948, when Nobert Wiener, one of the founding members of the group, published an influential book with this title. The term cybernetics derives from the Greek word kybernetes (κυβερνήτης), which means the "steerman" or "governor," and is often used in Greek to refer to the captain of a boat or airplane.[1] In his book Wiener wrote that they had decided to call the "entire field of control and communication theory, whether in machine or in the animal by this name." He further justified his choice in the following way:

> "In choosing this term we wish to recognize that the first significant Paper on feedback mechanisms is an article on governors, which was published by Clerk Maxwell in 1868, and that governor is derived from a Latin corruption of the Greek kybernhths. We also wish to refer to the fact that the steering engines of a ship are indeed one of the earliest and best-developed forms of feedback mechanisms" [Wiener, 1948/2019].

The proposition of the group was based on the principles of information-

---

1 Although Wiener makes refers to paper by Clerk Maxwell, the term was first suggested in the first half of the 19th century by the French physicist André-Marie Ampère to refer to the science of control of governments. See:https://www.britannica.com/science/cybernetics, accessed 04/09/2021

feedback machines such as the steering engine of a ship, which Wiener used often as an example in his book, or the thermostat that controls a furnace. The group proposed that such machines can explain how living systems function and interact with their environment, from the level of a single organism to that of a whole society. The information-feedback machines are understood as operating in a cyclical flow of information, as an input and output function in the machine while in interaction with its environment. Wiener considered that our nervous system exhibits such circular processes of information when information is received by the muscles and then re-enters the nervous system through the senses [Wiener, 1948/2019].

A feedback control system could be a machine or living organism as both have sensors, effectors, an operating system or brain, and channels of communications with the external world. Wiener perceived the psychological concept of homeostasis as directly related to a feedback-control system, as it addresses the body's ability to regulate itself by maintaining constant blood pressure and other vital operations. Disordered states of operation were also often parallelized and legitimized through health disorders. For example, in the introduction to Cybernetics, Wiener, when describing how an excessive feedback mechanism in a system is a defect, gives the example of the nervous system feedback loop that occurs once someone picks up a pencil. He argued that in the act of picking up a pencil, an excessive feedback mechanism would be like a purpose tremor due to brain injury. In this condition the system "overshoots the mark and goes into uncontrollable oscillation" [Kline, 2015; Wiener, 1948/2019]

Wiener considered problems of control engineering to be inseparable from communication engineering, as both deal with the control and flow of information. Regarding communication systems, he considered the "message" to be "a discrete or continuous sequence of measurable events distributed in time" -- a time series [Wiener, 1948/2019, p. 8-9]. Communication became a problem of statistics, namely a "theory of the amount of information, in which the unit amount of information was that transmitted as a single decision between equally probable alternatives." Wiener's theory of communication engineering overlaps in many aspects with Claude Shannon's popular and established Information Theory, which was published at the same time in 1948. Both Wiener and Shannon dealt with information as patterns transmitted in communication systems -- either human systems or machine systems -- and they both based their theories on the physical concept of entropy.

In thermodynamics, entropy measures the energy in a closed system that is unavailable to be converted into mechanical work, which is usually considered equivalent to the measurement of the system's disorder because mechanical work is obtained from ordered molecular motion. Thus, entropy can also broadly be defined as the degree of disorder or uncertainty in a system.[1] Wiener writes that the measuring of the amount of information, naturally relates to the notion of entropy; "Just as the amount of information in a system is a measure of its degree of organization, so the entropy of a system is a measure of its degree of disorganization: and the one is simply the negative of the other" [Wiener, 1948/2019, p. 8-9].

Wiener defined information as negative entropy (predictability in communication), which means that with the increase of randomness or disorder in the selection of messages, less information will be transmitted. On the contrary, Shannon defined information as equivalent to positive entropy (unpredictability in the communication). However, when Shannon and Wiener exchanged letters commenting on the opposite sign they used in the entropy formula, they seemed to agree that this difference did not have any real significance. Shannon asked Wiener:

> "You consider information to be negative entropy while I use the regular entropy formula...with no charge in sign. I do not believe this difference has any real significance but is due to our taking somewhat complementary views of information...We would obtain the same numerical answers in any particular question. Does this diagnosis seem correct to you? Wiener agreed, saying "I think that the disagreements between us on the sign of entropy are purely formal, and have no importance whatsoever" [quoted in Kline, 2015, p. 14].

Shannon ended up developing a much more extensive theory of information than Wiener, and Shannon's theory is still the main reference in information studies. Shannon's theory of communication is broad enough to address a range of phenomena that includes exchange of information and processes in which one person or thing affects another. The word "communication" is used by Shannon to address "not only written and oral speech, but also music, pictorial arts, theater, ballet, and in fact all human behavior" -- in addition, of course, to procedures involving connections for tracking airplanes and guiding missiles [Shannon and Weaver, 1948/1998, p.2].

The basic principles of his model of communication are illustrated in his schematic diagram provided in The Mathematical Theory of Communication [Shannon and Weaver, 1948/1998] [FIG. 16].The system essentially consists of an information source, a transmitter, a channel

---

1 https://www.merriam-webster.com/dictionary/entropy ; google dictionary; https://www.britannica.com/science/entropy-physics; accessed 03/09/2021

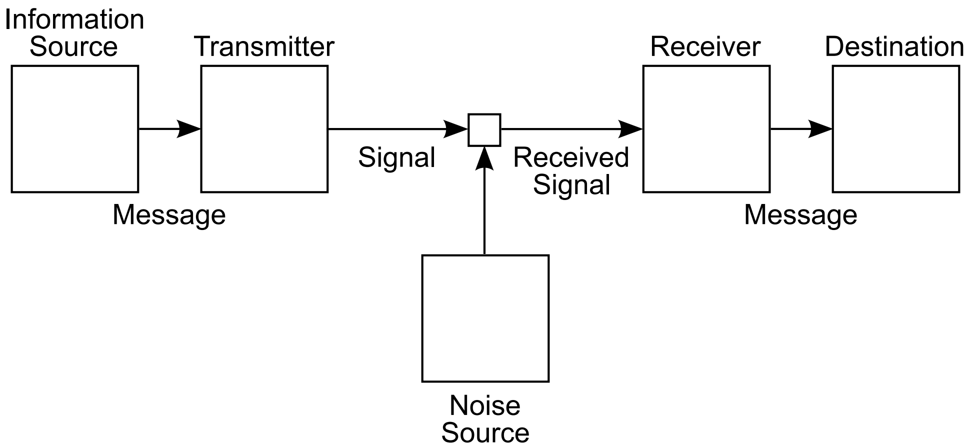


FIG. 16 Shannon's communication model. Original source: Shannon and Weaver, [1948/1998]. Source: Wikipedia org/ Public Domain

(with a noise source), a receiver, and a destination (recipient):

> (1) The information source produces a message or sequence of messages that can be of various types. The message can be a sequence of written or spoken words, or letters. It can also be a single function of f(t) time, as in radio signals, or more than one function of time or several functions of several variables. Shannon gives as an example the message needed in television: "here the message may be thought of as a function f(x,y,t) of two space coordinates and time, the light intensity at point (x,y) and time t on a pickup tube plate" He also gives the example of a color television, where in that case the message "consists of three functions f(x,y,t), g(x,y,t), h(x,y,t) defined in a three dimensional continuum"
>
> (2) The transmitter encodes the message from the information source and converts into a signal suitable for transmission over the communication channel. The encoding process may require sampling, modulation, compression or conversion to the appropriate signal. For example, in telegraphy, the transmitter codes written words in dots and dashes which are sequences of current of shorter or longer length. In telephony, sound pressure converts into a proportional electrical current.
>
> (3) The channel is the medium used to transmit the signal. It could simply be a pair of wires, a band of radio frequencies, a beam of light, and so on. The transmission of the signal through the channel adds noise to the signal. The noise is represented as an additional source of information that becomes combined with the incoming signal. The incoming signal together with the added

noise compose the signal received by the receiver.

(4) The receiver decodes the message. The receiver typically performs the inverse operation of the transmitter: it encodes the signals into a message and sends it to its destination.

(5) The destination is essentially the recipient of the message, which can be a thing or person, as is the case of the information source; there can be two people or two machines interacting. Shannon gives an example in simple words: “When I talk to you, my brain is the information source, yours the destination; my vocal system is the transmitter, and your ear the associated nerve is the receiver.”

In developing his model of communication, Shannon was interested in providing answers to the following matters: (1) the measurement of the amount of information; (2) the measurement of the capacity of the communication channel; (3) the characteristics of the coding process (encoding) of a message; (4) the characteristics of noise and how it affects the message; and (5) the nature of the message, if it is continuous (as in music), discrete (as in telegraphy), or mixed, and how these affect the communication process. Shannon was primarily interested in how an information system -- a system mathematically defined-- affects the meaning of a message and not the other way round; how semantics affect information. He writes that “the semantic aspects of communication are irrelevant to engineering aspects (..) but this does not mean that the engineering aspects are necessarily irrelevant to the semantic aspects” [Shannon and Weaver, 1948/1998, p.7]

It is important to note that the produced message in Shannon’s model of communication is essentially a message selected out of possible messages, as Shannon defines information as the amount of uncertainty in the selection of messages. As Kline notes, this makes sense intuitively because “the more uncertain we are of what message will be selected, the more information we receive. The more certain we are, the less information we receive.” [Kline, 2015]

Information, according to Shannon’s model, is “the measure of one’s freedom of choice when one selects a message.” Thus, the model is essentially based on statistics and probability theory. In simple cases, the amount of information is measured by the logarithm of the number of the available choices. If we have only two choices -- for example, “yes” and “no”-- then the amount of information is 1 (logarithm base 2 of 2). This unit of information is one bit. If one has 16 messages to choose from, the amount of information is 4 bits, as log(2) 16= 4. [Shannon and Weaver, 1948/1998]

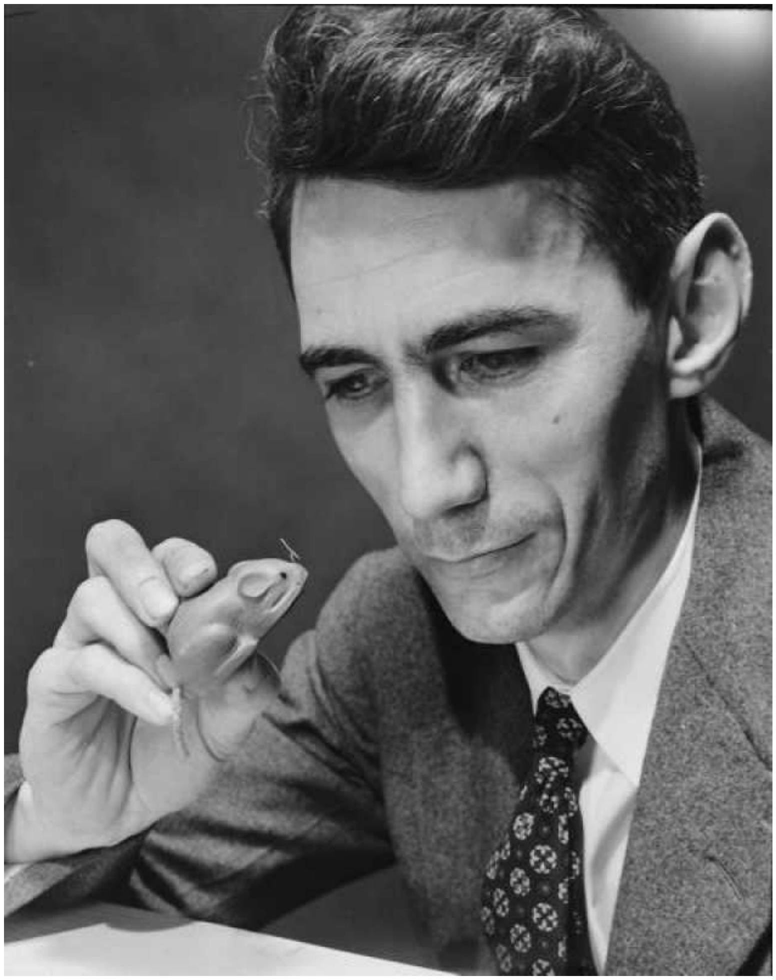


FIG. 17
Claude Shannon, holding Theseus, the mouse of the Theseus Maze. Source: Wikimedia Commons

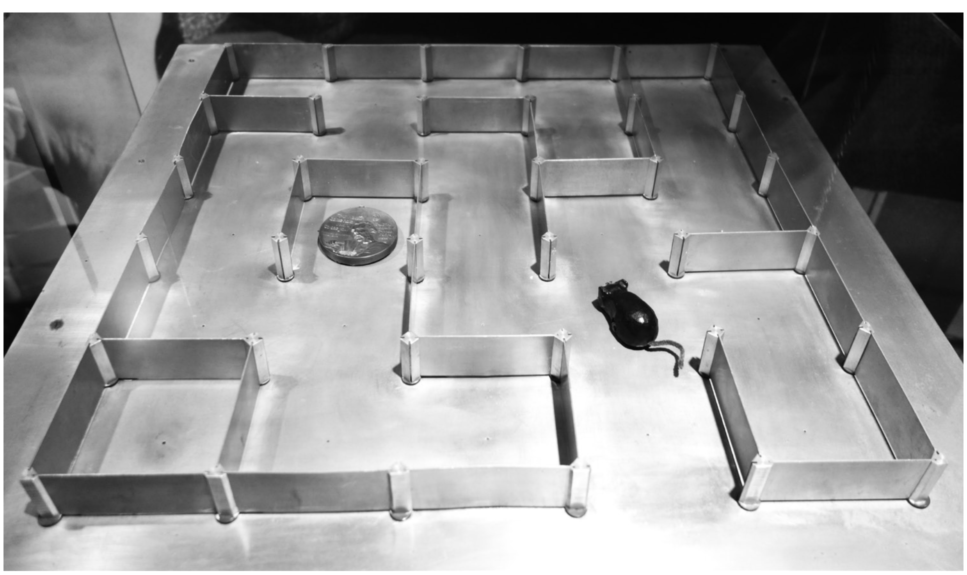


FIG. 18
Theseus Maze by Claude Shannon, 1952 - MIT Museum; Exhibit in the MIT Museum, MIT, Cambridge, Massachusetts, USA. Source: Wikimedia org / Public Domain

Before publishing his Mathematical Theory of Communication, Shannon had developed a model for decrypting information, which was declassified later, in 1945. According to Shannon, the selection of the message and the key had a priori probabilities that were known to the enemy. Every time the enemy would intercept the cryptogram, a new set of probabilities would be calculated. The set of a posteriori probabilities is the enemy's knowledge of the message and key after the interception. Regarding Shannon's model of the general secrecy system, Kline writes, "perfect secrecy was defined as the situation where the enemy's a posteriori probabilities equaled his a priori probabilities; he would be no better off after intercepting the cryptogram than beforehand" [Kline, 2015, p.33]

In 1951, in addition to his theoretical models of communication, Shannon created a physical model of a maze-running mouse, called Theseus, which showed the logic of the telephone system. The maze consisted of rearrangeable partitions organized in an orthogonal grid; the mouse was made of wood containing a magnet. A metal cheese was also placed in the maze. The mouse, Theseus, was programmed to navigate the maze until it reached the cheese. The idea was that the Mouse would essentially learn through a feedback process how to navigate the maze without bumping into walls, and when the walls were rearranged Theseus was able to re-learn the solution. Theseus is one of the earliest examples of machine learning, relying on feedback learning to understand its environment using a combination of relays and magnets [Kline, 2015] [FIG. 17-18].

Models for physical feedback mechanisms were also popular among the group of cyberneticians. Perhaps the most famous physical model created by the group's members was Ross Ashby's homeostat [FIG. 19]. Ashby was studying the adaptive behavior of systems through a relation of input, output variables, and feedback loops between their components. The homeostat was the culmination of Ashby's research into systems that can maintain their equilibrium through continuous adaptation. The homeostat was essentially an unknown "black box" with known inputs and outputs. It consisted of four interconnected units with switches and electromagnets. The output of each unit was connected to the input of the other unit in a reconfigurable manner. The electromagnets were on top of each unit; each had a needle which was in contact with a metallic liquid. When the state of one of the magnets changed it would cause a change of the state of the rest of the magnets until they would all again reach an equilibrium state [Kline, 2015; Ashby, 1952/1960].

One of the interconnected units of the homeostat took on the role of the "environment" and the rest the role of the "organism," thus modelling the process of adaptation of an organism to its environment. Ashby's aim was to show that a deterministic mechanism can demonstrate non-

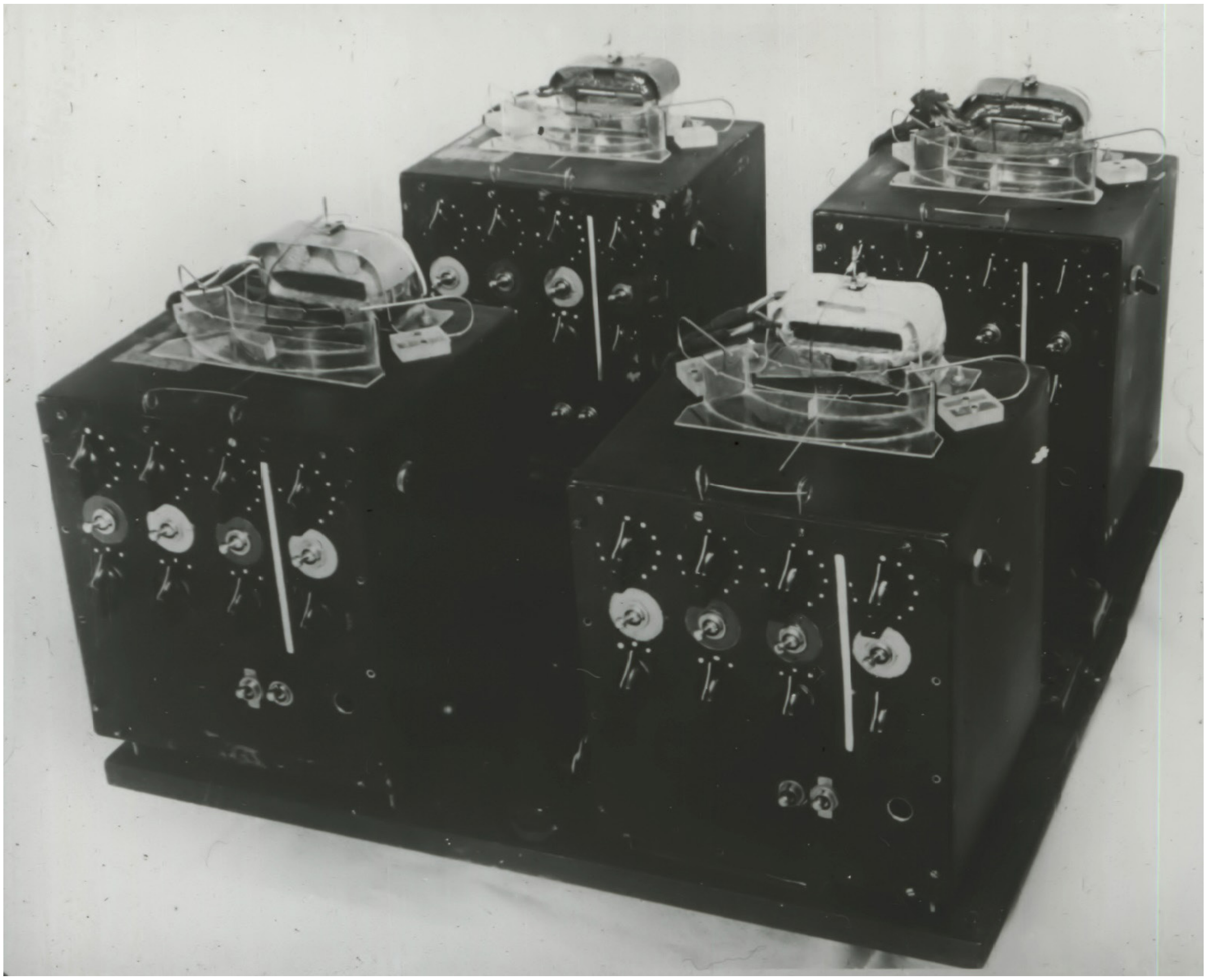


FIG. 19
Ross Ashby's *homeostat* built in 1948. Source: Wikimedia Commons.The homeostat was designed as a "black box" with known inputs and outputs. It consisted of four interconnected units with switches and electromagnets. The output of each unit was connected to the input of the other unit in a reconfigurable manner. The electromagnets were on top of each unit; each had a needle which was in contact with a metallic liquid. When the state of one of the magnets changed it would cause a change of the state of the rest of the magnets until they would all again reach an equilibrium state [Ashby, 1952/1960].

deterministic behavior. For Ashby, as well as other members of the group, the goal was to show that although mechanistic in nature, an adaptive machine can be as adaptive as the human brain. In Design for a Brain [Ashby, 1952/1960], where he presented the homeostat, Ashby formally and diagrammatically described adaptive systems along with everyday scenarios for their explanations. One such scenario is with the cat and the fire:

> “When a kitten first approaches a fire, its reactions are unpredictable and usually inappropriate. It may walk almost into the fire, or it may spit at it, or may dab at it with a paw, or try to sniff at it, or crouch or ‘stalk’ it. Later, however, when adult, its reactions are different. It approaches the fire and seats itself at a place where the heat is moderate. If the fire burns low, it moves nearer. If a hot coal falls out, it jumps away. Its behavior towards the fire is now ‘adaptive.” [Ashby, 1952/1960, p.12]

In the cat-fire example, it is the cat’s behavior that is primarily adaptive to the fire, whereas the fire’s state is basically unaffected by the cat’s behavior. Thus, seen as a system the cat-fire model has more of a one-way response, as the fire affects the cat more than the cat affects the fire. However, Ashby notes that, through her body movement, the cat manages to manipulate the environment by changing the pattern of sensory stimuli that affects her body: “the various stimuli from the fire, working through the nervous system, evoke some reaction from the kitten’s muscles” and “equally the kitten’s movements, by altering the position of its body in relation to the fire, will cause changes to occur in the pattern of stimuli which falls on the kitten’s sense-organs.” [Ashby, 1952/1960, p.38] In explaining systems with feedback, Ashby chooses an example with a more equal two-way impact between the organism and its environment -- the example of the ‘butterfly and the bird’:

> “Consider a butterfly and a bird in the air, the bird chasing the butterfly, and the butterfly evading the bird. Both use the air around them. Every movement of the bird stimulates the butterfly’s eyes and this stimulation, acting through the butterfly’s nervous system, will cause changes in the butterfly’s wing movements. The movements act on the enveloping air and cause changes in the butterfly’s position. A change of the position immediately changes the excitations in the bird’s eye, and this leads through its nervous system to change movements of the bird’s wings. These act on the air and change the bird’s position. So the processes go on. The bird has as environment the air and the butterfly, while the butterfly has the air and the bird.” [...] “The organism affects the environment, and the environment affects the organism: such a system is said to have ‘feedback.” [Ashby, 1952/1960, p.87]

Regarding what can be considered as environment Ashby gives the following definition: “ Given an organism, its environment is defined as those variables whose changes affect the organism, and those variables which are changed by the organism’s behavior.” [Ashby, 1952/1960, p.36] In describing what he calls the “ultrastable” system, Ashby returns to the kitten example. Ashby provides some formal definitions of the system through the incorporation of the variables of the kitten-fire system. In doing so, he uses a series of diagrams to explain the model step by step:

> (1) The first diagram shows the organism in interaction with its environment. R is the system of the organism, in this case the kitten. Although the kitten is the one primarily affected by the environment, the system is still depicted as a two-way interaction.
>
> (2) In the second diagram, in the cat-fire system, the parameters S of the kitten’s behavior have been added. The kitten has a variety of reactions towards the fire -- i.e, coming closer to it, moving away from it. The parameters S have an immediate effect on the organism but not on its environment, and thus are depicted in the diagram as connected only with R.
>
> (3) In the third diagram, Ashby adds the essential variables. Ashby defines as essential variables, those variables of the organism that are affected in the system’s interaction. Here these are depicted as only affected by the environment. For example, an essential variable can be the felt temperature or the amount of pain which increases and decreases in response to the proximity to the fire. The essential variables need to be kept within a certain physiological range for the organism to maintain a state of equilibrium -- to maintain its homeostatic functions. Thus, the essential variables are here represented as a dial with a pointer, to show that they need to be kept within a certain range, and the dial is connected to the environment, as it is the only one affecting them.
>
> (4) In the fourth diagram, Ashby demonstrates the relationship needed for the kitten to adapt to the environment: while she cannot control the initial values of essential variables of the system, through the manipulation of her motor functions she needs to alter her environment to adjust the variables within proper limits. The environment acts as a “black box” to the cat as she is trying to control its output without being aware of its mechanisms. The kitten then is forced to proceed in a “trial and error” process, which is essentially a process of “gathering information” through which she will hopefully learn how to adapt to the system and not get burned.

> (5) In the fifth and final diagram, Ashby demonstrates what a successful adaptation looks like. Here the essential variables (dial) are connected to the kitten's behavior S. This is because the kitten manages, by going through the process of trial and error, to adjust to the impact of sensory stimuli from the environment, keeping them in the proper physiological range. Thus, a system where an organism can adapt itself to the environment needs to have two feedback loops: the first loop consists of sensory input providing information regarding the environment, and the second one provides information regarding the state of essential variables. The inner loop works as a feedback with each behavioral reaction, whereas the outer loop determines which behavioral reaction will occur.

Ashby provides the basic rule of adaptation by trial and error - an essential function of the ultrastable system - as follows: "If the trial is unsuccessful, change the way of behaving; when and only when it is successful, retain the way of behaving." This rule leads to the following two formulations: (1) When the essential variables are not within their normal range, no state of the kitten's behavior S is in a state of equilibrium; (2) When all the essential variables are within their normal range, every state of kitten behavior S is a state of equilibrium. For the second condition to occur, a system needs to be a system with a double feedback mechanism, as described earlier.

In addition to Theseus and the Homeostat, more adaptive machines were built during the time of the Cybernetics era. For example, the moth/bedbug, developed by Wiener's lab, was a robot that had a light-seeking and a light-avoiding behavior and used two feedback paths to simulate two types of tremors: an intention tremor and a parkinsonian tremor. The first occurs through an overloading of voluntary feedback and the second by an overloading of postural feedback. Another project, developed by Grey Walter, was that of the two "tortoises'' that model emergent physiological and psychological behaviors. The tortoises could sense the light and presence of physical objects and could also "recognize" themselves and each other, and eventually included memory circuits that allowed them to learn through the mechanisms of their sensory interaction [Kiline, 2015].

2.3.2. HUMAN-MACHINE SELF-REGULATING SYSTEMS

Beyond having the human nervous system as a model for machines' adaptive behavior, and the machine as a metaphor for the brain and human behavior, some of the cybernetic group's projects involved the actual hybridization of humans and machines. Such examples included projects on medical cybernetics, also known as bionics, which led to the conception of cyborgs, as well as prosthetic mechanisms. A prosthetic mechanism developed by Wiener was the hearing glove. Sound waves were converted into electrical signals representing five octaves, which were then converted into mechanical vibration for each finger. The idea was that each phoneme would correspond to a unique tactile pattern. The purpose of the device was to act as a hearing aid for deaf people by aiding them to decode spoken words through the correlation of speech to tactile patterns [Kline, 2015].

The research field of bionics, which was influenced by the research of Warren McCullloch and Walter Pitts on neural nets and Norbert Wiener's cybernetic projects, emerged during the Cold War and was established by Heinz von Foerster through his work at the Biological Computer Laboratory University of Illinois in Urbana-Champaign, founded in 1958. Bionics was a fusion of biology and electronics. Von Foester used the "biological computer" to refer to computing processes mimicking biological processes. Soon after the emergence of bionics, in 1960, the term cyborg emerged, signifying a true fusion between machines and humans. The term was introduced in a paper by Manfred Clynes and co-authored by Nathan Kline, entitled "Drugs, Space, and Cybernetics: Evolution to Cyborgs" published in the journal Psychophysiological Aspects of Space Flight [Kline, 2015].

In the article, "Cyborgs and Space" [Clynes and Kline, 1960, based on the aforementioned article] Clynes and Kline express their vision about cyborgs and explain how their approach would aid humans to adapt to space and to practically any environment. The term cyborg is an abbreviation for "cybernetic organism." Although all organisms can be thought of as being cybernetic (as beings interacting with their environments), cyborgs are different in that they incorporate artificial mechanisms with chemical, physiological and electronic operations that allow organisms to maintain their homeostasis in their non-natural environments. The project is presented as a rather ambitious one, promising to overcome the limitations that biological functions such as breathing pose to us in dealing with environmental adaptation.

According to Clynes and Kline, we should not take for granted the fact that a fish cannot live outside water. Instead, we should find solutions that allow organisms to survive beyond their natural “field of operation.” As they rather provocatively argue:

> “If a fish wished to live on land, it could not readily do so. If, however, a particularly intelligent and resourceful fish could be found, who had studied a good deal of biochemistry and physiology, was a master engineer and cyberneticist, and had excellent lab facilities available to him, this fish could conceivably have the ability to design an instrument which would allow him to live on land and breathe air quite readily.”

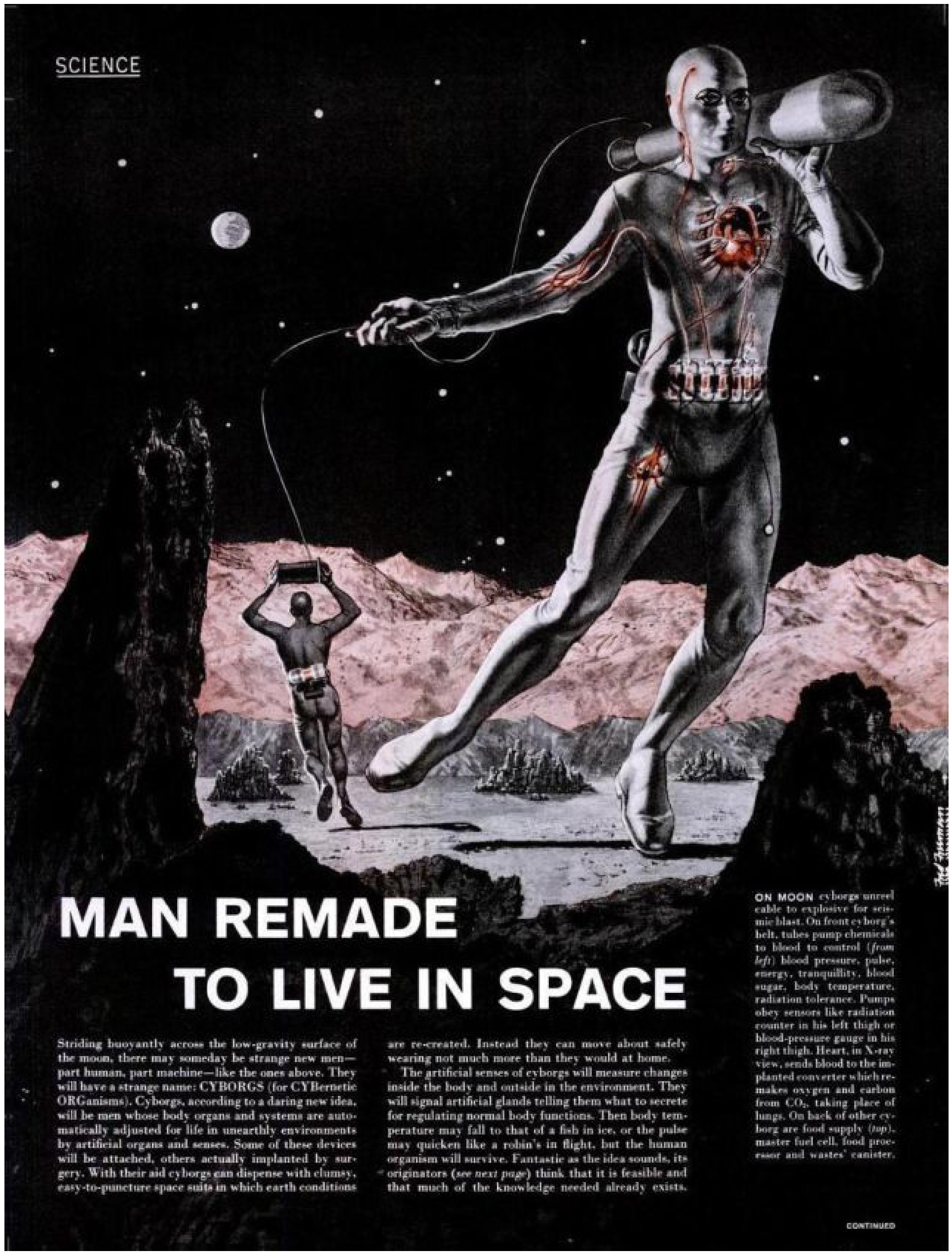
Making the analogy with the fish, Clynes and KIne suggest that for a human to truly adapt in space, the solution is not to encapsulate his environment – as in putting a water bubble around a fish out of the water -- but to create “self-regulating manmachine systems” that would function based on autonomous homeostatic functions without the need for conscious operations. These self-regulating manmachine systems can consist of a “combination of an osmotic pressure capsule with sensing and controlling mechanisms” that forms a continuous loop with the body adjusting its autonomic function. The mechanism would allow programmed delivery of necessary drugs to address physiological changes. Upon the sensing of the altered body states, the drug delivery would be automatic. At the time of the paper’s publication, the authors had tried implementing their mechanism in a cyborg mouse: they adjusted an osmotic pump under its skin “to permit continuous injections of chemicals at a slow controlled rate into an organism without any attention on the part of the organism.”

Cyborgs became a popular fantasy [FIG. 20], offering utopian scenarios of humans living in a technological and biological fusion that allowed them to extend the abilities their mind and body to become “superhuman.” In his book Cyborg: Evolution of the superman, Halasy [1965] helps spread this fantasy:

> “A new frontier is opening which allows us renewed hope.
> The new frontier is not merely space, but more profoundly the relationship of “inner space” to “outer space” - a bridge being built between mind and matter, beginning in our time and extending into the future (...) Consider a cyborg spaceman whose body is artificially cooled far below the normal 98.6 degrees to prolong life and permit him to exist on a bare fraction of the ‘fuel’ natural man would require. His body structure has been altered so that weightlessness does not harm him, and he is drugged or hypnotized to provide him with an artificial sense of gravity. Fed intravenously he produces no waste products. His cells are immune to radiation normally dangerous to man. Electronically

> amplified limbs permit him to move as required even during the extreme stresses of blast-off and reentry, or other high concentration maneuvers.” [p.7, 13]

FIG. 20
Painting by Fred Freeman portaying a cyborg, originally appearing in the July 11, 1960 issue of *LIFE Magazine*. Source: cyberneticzoo.com Accessed: 11/23/2021


SCIENCE

MAN REMADE TO LIVE IN SPACE

Striding buoyantly across the low-gravity surface of the moon, there may someday be strange new men—part human, part machine—like the ones above. They will have a strange name: CYBORGS (for CYBernetic ORGanisms). Cyborgs, according to a daring new idea, will be men whose body organs and systems are automatically adjusted for life in unearthly environments by artificial organs and senses. Some of these devices will be attached, others actually implanted by surgery. With their aid cyborgs can dispense with clumsy, easy-to-puncture space suits in which earth conditions are re-created. Instead they can move about safely wearing not much more than they would at home.

The artificial senses of cyborgs will measure changes inside the body and outside in the environment. They will signal artificial glands telling them what to secrete for regulating normal body functions. Then body temperature may fall to that of a fish in ice, or the pulse may quicken like a robin's in flight, but the human organism will survive. Fantastic as the idea sounds, its originators (*see next page*) think that it is feasible and that much of the knowledge needed already exists.

ON MOON cyborgs unreel cable to explosive for seismic blast. On front cyborg's belt, tubes pump chemicals to blood to control (*from left*) blood pressure, pulse, energy, tranquillity, blood sugar, body temperature, radiation tolerance. Pumps obey sensors like radiation counter in his left thigh or blood-pressure gauge in his right thigh. Heart, in X-ray view, sends blood to the implanted converter which remakes oxygen and carbon from CO_2, taking place of lungs. On back of other cyborg are food supply (*top*), master fuel cell, food processor and wastes' canister.

CONTINUED

2.3.3. AFFECTIVE COMMUNICATION AND COMPUTING

Although Manfred Clynes became famous after launching a Cyborg-cult, his main preoccupation was not space research but emotions. Clynes developed the theory of Sentics, which was essentially an emotion theory seen from a cybernetic perspective, as it utilized creatively invented instruments such as the “sentograph” – discussed below -- to measure emotions and sought to scientifically identify patterns in expression of emotion that would reveal their inner universal essence. Uncovering emotions’ universal essence in terms of a formal pattern would allow him to unlock the secrets of non-verbal affective communication, including haptic communication and gestures, music, dance, and more. Clynes believed that behind each of the particular modalities of communication, there was a common form for the generation of each emotion, which he named essentic form [Clynes 1978; Clynes 1980].

Clynes was certainly a follower of evolutionary and basic theories of emotion theories (as opposed to theories that are culturally based). He believed that one can experience emotions most purely through their essentic forms -- their essential, distinguishable, universal, patterns. In a similar way that music, as a pure sequence of tones can generate one emotion or the other, he believed that as a pure sequence of essentic forms, emotions could do the same. The essentic forms were independent of their means of expression, could be expressed in any modality -- music, movement, gesture, and so on -- and even revealed themselves in the painting of great artists [Clynes 1978; Clynes 1980].

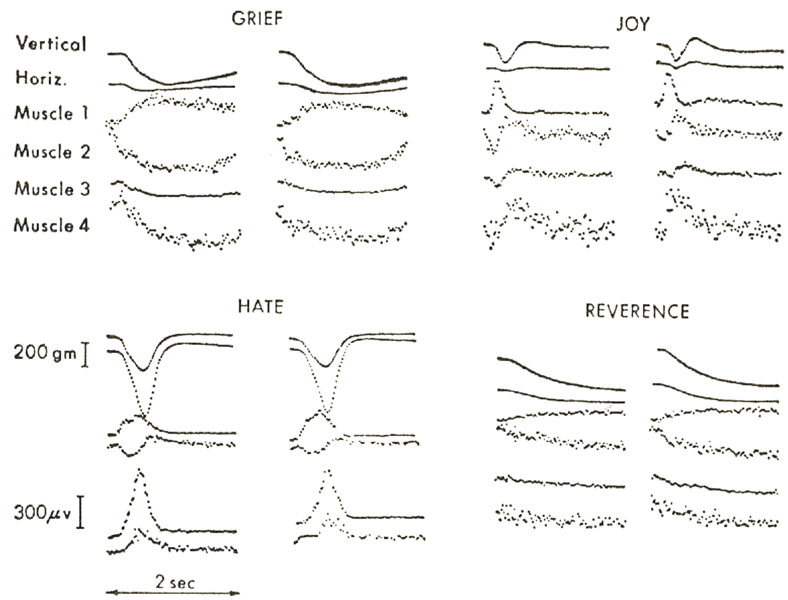
To measure these essentic forms, Clynes created the “sentograph,” a machine that measured the pressure applied from a subject’s finger in the form of a vector, keeping track of the pressure’s vertical dimension and horizontal dimension [FIG. 22]. Measuring the form of emotions through the pressure of a finger offered a convenient experimental way to record the universal forms of emotions. The directionality of the force was measured in the form of pushing or pulling, as according to Clynes, emotions have the tendency to either attract or repulse. Having subjects pushing the button of the sentographs for two seconds while having been instructed to feel a series of specific emotions, Clynes developed essentic forms for those specific emotions. The essentic forms were composed of two lines, the upper being the result of the horizontal pressure component and the lower being the result of the vertical pressure component [Clynes, 1978] [FIG. 21a-b].

For Clynes, the dynamic patterns he depicts in the essentic forms are more than a representation. Clynes suggested that certain affective qualities, could be used to express the same meaning through different forms of embodiment. For example, in The Communication of Emotions [Clynes, 1980] Clynes describes how laughter has its own essentic form which can be recorded as a breathing/voice output pattern. He then contends that if we try to reproduce the same pattern, not as the dynamics of our breathing but as the dynamics output of our finger pressure, we will experience the same feelings as a kind of “silent finger laughter” [FIG. 23]. He describes the invention of the “finger laughter as follows:

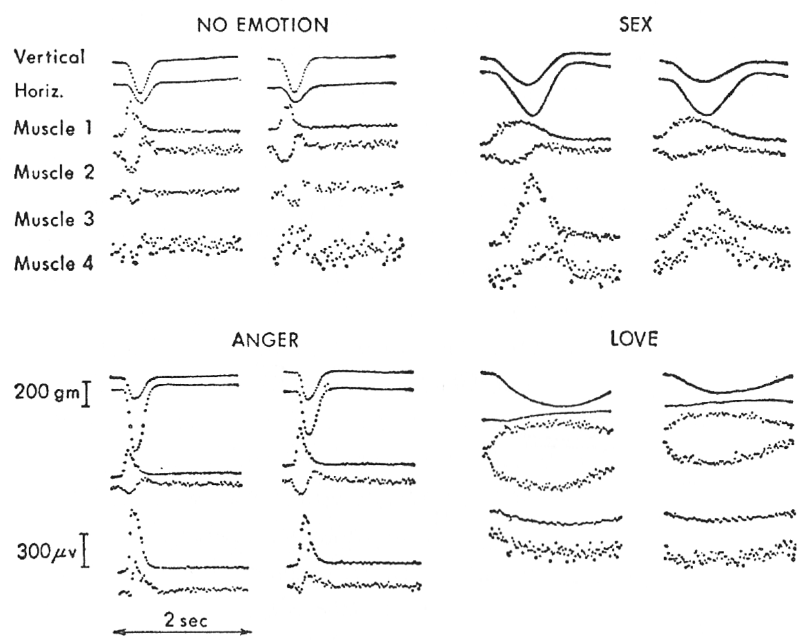
> “If finger pressure is substituted at the same dynamic rate and manner as the chopped voice, all of the characteristic experiences of laughter are produced, including the sense of funniness, tearing of the eyes, twinkling of the eyes, and even paroxysms of laughing. The mean repetition frequency of the chopped voice (the “ha’s) and of the repeated finger pressure is 5.03 Hz (±.18 SD). The frequency chosen by a person laughing using repeated finger pressure is the same that he uses when laughing in the usual ways.” [Clynes, 1980, p. 292]

Beyond aspiring to invent a new form of laughter and a universal sentic language, Clynes was perhaps one of the first to demonstrate the significance of the temporal parameters in emotion and communication of emotion in a computational manner. More recent computational approaches may approach the temporal aspect of emotions differently but still consider it as a matter of great significance and challenge. For example, in Affective Computing, Rosalind Picard [1997/2000] proposes a theoretical model for emotion and mood processing based on signals. To arrive at this model, Picard first explains to the reader the non-linearity of the nature of emotions by comparing emotional intensity to the striking of a bell. In the same manner that the sound of a bell presents itself as a curve, with its peak and decay, the feeling of an emotion might reach its high peak for a brief amount of time and then slowly subside. The intensity of an emotion, measured as arousal through the electrodermal activity (EDA), usually has a fast onset, and a slow decay.

Like sound responses to repeated bell strikes, repeated emotional responses to a triggering event will have a cumulative result, leading to higher and higher intensity. As with the sound of a bell, which cannot reach indefinitely high levels of volume, there is a limit to the experience of an emotion, where the feeling will saturate, or the system will break. A break in an emotional system could be the point at which someone “flips” or has a nervous breakdown – like a bell being broken into pieces. Picard also makes an analogy between the physicality of the bell and a person’s disposition: as the bell’s shape and material will influence both the tonality and intensity of the sound, a person’s disposition -- being in a happy or



a



b

FIG. 21a-b
Comparison of sentograms of the essentic forms of various emotions: (a) Grief, Joy, Hate, Reverence; (b) No Emotion, Sex, Anger, Love. The sentograms were composed of two lines expressing the finger's pressure horizontal component (upper line) and vertical component (bottom line) as measured by the sentograph, as well as measurements of other muscle potentials from the forearm, upper arm, front shoulder, and back [FIG. 22] [Clynes, 1978]

FIG. 22
Clynes' "sentograph," a machine that measured the essentic forms through the pressure applied from a subject's finger. Source [Clynes, 1978]

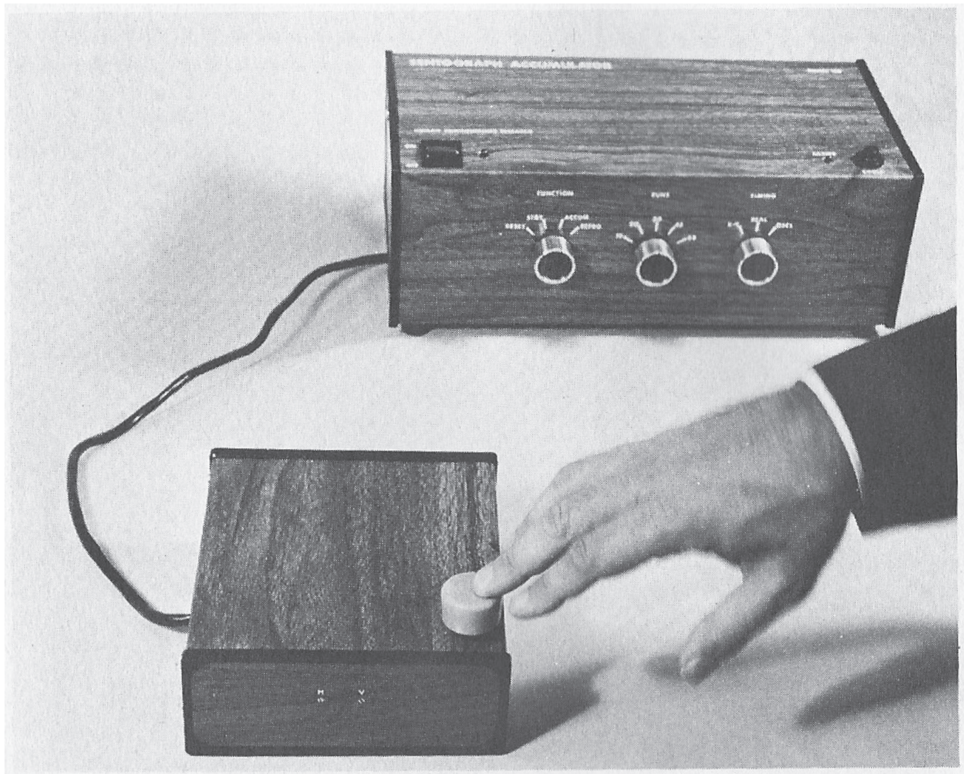
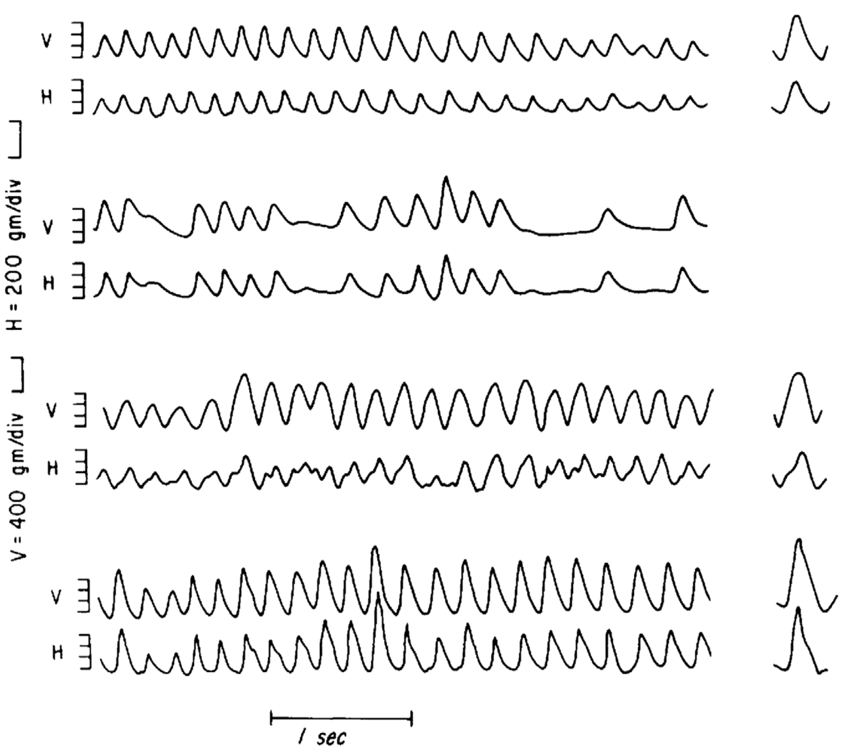


FIG. 23
Finger laughter. "Various emotional types of voiceless motoric laughter showing vertical and horizontal components of finger pressure" as measured by the sentograph [FIG. 22] [Clynes, 1980]



sad mood -- will influence the response to a triggering event.

A model that expresses the dynamic transformation of emotions through time, has been proposed by Picard [1997/2000] as a signal representation system, accounting for emotional intensity and valence. The model accounts for the non-linearity of expression of emotions, as well as for personality traits, through sigmoids (whose slope differs according to different personalities) that filter the positive and negative inputs. In the model, the positive and negative disposition of a person is represented by positive and negative sigmoids which determine the threshold of an influence one has towards positive and negative events (a happier person will tend to let more positive emotion events influence them). The intensity levels of emotional events are represented as bars occurring at different points in time, while the final mood will be the accumulation of the impact of the triggering emotional events as these are filtered by a person's disposition.

The previously described model of affect is only a small proposal of the much broader framework of Affective Computing that has now become a large field in computing and Human Computer Interaction. First proposed in her book Affective Computing, Picard argued for the integration of emotions in computing systems, as these had been left out of the machine intelligence equation. It used to be the norm for researchers working in AI and computing systems to assume that systems that reason using logic can simulate human intelligence and respond to human needs. However, as our discussion on Damasio's work demonstrates, emotion has an impact on our decision and reasoning, thus Picard argued that to make computers intelligent, we need to make computers recognize and express human emotions; indeed, the only way to make computers truly intelligent is to make them adapt to human intelligence, which to a great extent relies on emotions [Picard,1997/2000].

Like any computing model and system, affective computing, deals with information. Discussing information in affective systems in response to Shannon's theory, Picard argues that the amount of affective information a system can carry can be described as its affective bandwidth. She also uses the term Affective Information to refer to the entropy of the affective part of the signal, the required bits of information needed for the message to be carried effectively. Given these definitions, she argues that we speak of affective channel capacity when referring to different communication media. For example, she discusses how email as a medium has less affective capacity than a videoconference or an in-person communication. This happens because more sensory modalities are available during in-person communication to convey a message; we can read, see someone's expression and posture, hear the message, and so on.

In Affective Computing, what can be a breakthrough regarding emotional communication and in part motivates my work in this dissertation is what Picard [1997/2000, p. 57] describes as the increase of affective bandwidth – i.e., the increase of capacity for affective information beyond the limits of current communication channels:

> “Might technology increase affective bandwidth? Virtual environments and computer-mediated communication offer possibilities that we do not ordinarily have in person-to-person communication. Potentially, communication through virtual environments could provide new channels for affect -- perhaps, as one idea, via sensors that detect physiological information and relay its significant information. In this way, computer-mediated communication might potentially have higher affective bandwidth than traditional ‘in person’ communication.”

3. AFFECTIVE MATTER STUDIES

3.1 [STUDY I] AFFECTIVE SLEEVE I: STUDY ON PROMOTING CALMNESS IN A STRESS-INDUCING ENVIRONMENT USING A PROGRAMMABLE NITINOL-BASED SLEEVE WITH HAPTIC ACTION

The programmable sleeve and controlled study were conducted in collaboration with graduate student Jackie Berry in the context of the course "Affective Computing," taught by Professor Rosalind Picard at MIT. The controlled study was supervised by Professors Terry Knight and Rosalind Picard. A first publication of the study appears in the proceedings of the 2019 Human Computer Interaction International Conference [Papadopoulou et al., 2019]. Additional arguments, context material, and interpretations of the results appear in this section as part of Affective Matter.

3.1.1. INTRODUCTION AND SCOPE

As discussed in the introduction emotion self-regulation via Affective Matter also constitutes a case of emotion communication, which, contrary to interpersonal communication, operates intra-personally: it allows physiological manifestations of one's own emotions to inform one's own mind. When operating intrapersonally, Affective Matter can possibly function on both the conscious and subconscious level. At the conscious level, Affective Matter can, in principle, make us aware of the bodily expression of our emotional state. At the subconscious level, Affective Matter can, in principle, regulate the mind directly through the reprogramming of its autonomic functions via the programmable material environments interfacing with the body.

Aiming to test the impact of Affective Matter in emotion self-regulation, this study measures the benefits of a developed affective sleeve with haptic action in reducing the psychophysiological symptoms of stress. The decision for testing the impact of haptic sensations was taken because of the physical and emotional health benefits of touch, as discussed in chapter 2.3.1. The haptic action of the sleeve consists of the sensations of slight warmth and pressure, which are the main sensations composing the feeling of being touched. The haptic action is programmed to be produced in a rhythmic manner at a pace correlated with the wearer's relaxed breathing rate.

It is hypothesized that pacing the haptic action more rapidly than the wearer's relaxed breathing rate will increase the wearer's psychophysiological symptoms of stress, and that pacing the haptic action at the wearer's relaxed breathing rate will reduce these symptoms. We arrived at this hypothesis because of the reviewed effects of controlled breathing and the tendency of our bodily functions to synchronize with external and internal rhythms through the processes of interpersonal and intrapersonal entrainment. This study is informed by previous studies on interoceptive awareness, tactile and guided breathing interventions using rhythmic sensory stimuli, briefly reviewed in the following section.

3.1.2. PRIOR STUDIES

As discussed in chapter 2.1.2, cultivating awareness of one's body and its internal functions helps to reduce anxiety and promote calmness. For example, Canales-Johnson et al. demonstrate, through an intervention of auditory heartbeat feedback, external sensory stimuli can help promote and guide our interoceptive awareness [Canales-Johnson, A., et al., 2015] Controlled breathing is another way we can achieve better awareness of our body and regulate our emotions. Beyond the yogic pranayama technique [chapter 2.1.3a], technological interventions can provide health benefits through breathing regulation. For example, Elliot et al. [2004] demonstrated the positive effects of device-guided breathing on lowering blood pressure. In addition, several mobile applications have been developed that achieve breathing control through visual, auditory, or tactile stimuli [Bumatay et al., 2017; Roquet and Sas, 2018]

As discussed in chapter 2.1.4, although good levels of interoceptive awareness are associated with good emotional health, very high levels of interoceptive awareness are associated with high anxiety levels and emotion dysregulation [Dunn et al., 2010; Pollatos et al., 2007; Kanbara and Fukunaga, 2016]. Studies have shown that false interoceptive awareness (providing sensory feedback that is either higher or lower than the pace of bodily functions) can regulate the heart activity or breathing activity so as to reduce anxiety levels [Costa et al., 2016; Ghandeharioun and Picard, 2017]. For example, Ghandeharioun and Picard showed that barely perceivable auditory and visual stimuli produced on a computer screen rhythmically oscillating to match participants' relaxed breathing rates, increased their focus and calmness [Ghandeharioun and Picard, 2017].

Haptic interventions and devices with therapeutic effects have also been developed. Since the Sensory Integration method initially developed by Ayres in the 1960's and 70's [Ayres, 1972] occupational therapists have been using a variety of deep pressure stimulation methods and tools to promote calmness or improved proprioception to individuals with autism, attention deficit disorders, anxiety and trauma. Such methods include massage, especially designed wraps or pillows, weighted blankets [Eron et al., 2020], pressure garments [Guinchat V., et al., 2020], and weighted vests [Stephenson and Carter, 2009]. The benefits of such methods, widely used in practice, have also been confirmed in scientific studies [Chen et al., 2013; Eron et al., 2020; Bestbier and Williams, 2017]. Beyond the typical passive weighted vests, available products in the market, such as the Squease vest,[1] can produce the feeling of pressure

---

1 https://www.squeasewear.com/ accessed 10/02/2021

through user-controlled pneumatic pressure.

Many of the devices and garments currently used for deep pressure relaxation are inspired by the Squeeze Machine, invented by Temple Grandin in 1965 while she was a college student [Grandin, 1992; Grandin and Scariano 1986]. Being on the autism spectrum, Grandin had oversensitivity to touch by others, and developed the machine to help her become accustomed to touch while benefiting from its calming effects. The machine consists of two padded boards, hinged at the bottom to form a V-shape. The user lies inside the machine and between the patted boards, and is able to control the amount of pressure through a pneumatic valve, connected to an air cylinder that can pull the boards together [Grandin, 1992].

Researchers in human computer interactions have recently started to explore solutions that take advantage of current sensor technologies to automate the pressure response [Goncu-Berk, 2021]. To my knowledge, our study was the first to design and evaluate through testing a wearable that combines breathing regulation with haptic feedback in the form of personalized, based on one's physiology signals, rhythmic felt pressure [Papadopoulou et al., 2019]. To my knowledge, our study was also the first to explore and evaluate through testing the impact of a wearable sleeve (rather than a vest) on promoting calmness [Papadopoulou et al., 2019]. Recent studies have also started to explore methods that combine breathing regulation and haptic feedback in other wearable forms [Choi et al., 2021].

3.1.3. METHODS

3.1.3a. THE DESIGN OF THE AFFECTIVE SLEEVE I

In the first phase of the design of the sleeve, we explored ways to program material behavior to achieve the sleeve's haptic action and decided to use nitinol wire to provide controlled shape transformation of the sleeve [FIG I. 1-8]. Nitinol is a shape memory alloy that can be programmed to change into a predefined shape if preheated to above a certain temperature in that desired shape. Given that we wanted the sleeve's haptic action to consist of both thermal and pressure sensations, the benefit of using nitinol was that we could produce both sensations at once: the heating of the nitinol wire would provide the thermal sensation while simultaneously causing the wire to change shape, producing the feeling of pressure on the skin. Another advantage was that nitinol wire is readily available on the market, allowing other researchers to reproduce the sleeve design.

The disadvantage of using a nitinol wire is that it has a non-reversible programmable behavior. Having a non-reversible programmable behavior means that while the wire can always return to predefined shape A after it has been deformed into a shape B, it cannot be programmed to go back to the shape B. This presents a problem in designing a sleeve that needs to actuate repeatedly and change from shape A to B and back to A to produce a "pressure and warmth" and "no pressure no warmth" cycle. To achieve the repeated transformation, we decided to couple the nitinol wire with another material to mechanically force the sleeve to go back to shape B after having been reset to shape A. Our first experiments consisted of a simple series of prototype iterations using nitinol wire in the form of a spring and a stiffer material like plastic or heavy felt fabric, sometimes with the addition of elastic material [FIG I. 1-2]

Two main approaches were tested in the design of the sleeve. In the first approach the main part of the sleeve consisted of a stiff material in a U-shape. The nitinol wire connected its two edges in the form of a spring, allowing for the change transformation. The nitinol wire was shaped as a spring and preprogrammed to return to its shrunken, condensed shape upon heating. Because of the tension created by the U-shaped material, when the nitinol spring cools down, it expands in length. When nitinol is heated, it forces the sides of the U-shaped material to come closer, creating the feeling of slight pressure to the wearer. When the nitinol cools down, the sides of the U-shape open up, the sides then no longer touch the skin, and the feeling of pressure ends [FIG I. 2].

FIG I. 1
Series of prototype iterations to test shape change and haptic action using nitinol wire, fabrics, elastic bands and springs

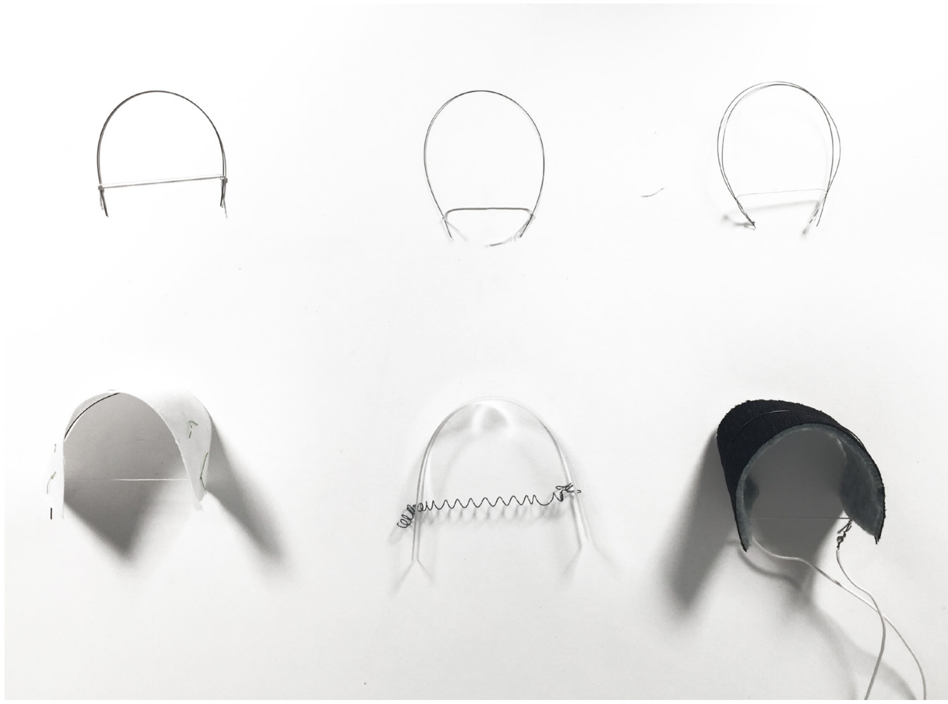
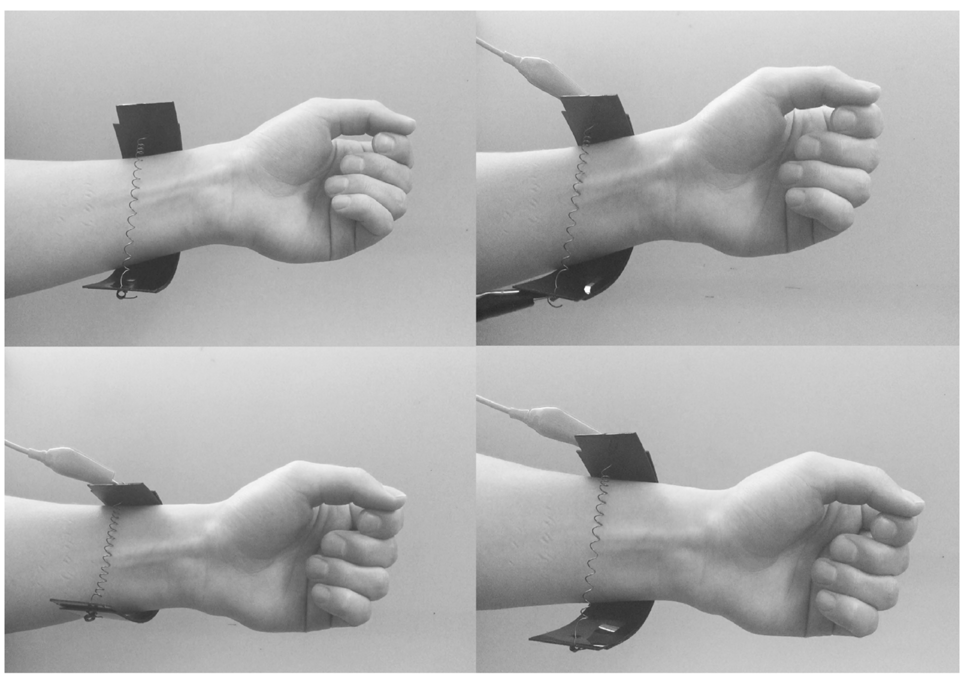


FIG I. 2
Early prototype of shape changing cuff producing warmth and slight pressure when current passes through the nitinol spring



The first design approach we explored yields repeatable results and achieves a satisfying degree of transformation. Several disadvantages, however, prevented us from adopting it in the final sleeve design. First, it requires a strong and stiff material like plastic for the U-shape to achieve the desired transformation, and a great deal of power to change the state of the nitinol spring from its relaxed to tensed state. Moreover, only the bottom of the sleeve became heated, whereas we wanted the feeling of warmth to be distributed around the forearm. In addition, this design required using a stiff material like plastic, whereas we wanted to make something that looked and felt like a garment. Finally, needing to have the nitinol wire like as a spring significantly limited our design possibilities, as it could not be easily wrapped inside other materials.

The second design approach we explored -- and decided to move forward with -- was to bend the nitinol wire into a U-shape and use an elastic connector to attach the two ends of the U-shape. This approach is opposite to the one we first explored, as the wire is in mechanical tension when not heated. The nitinol wire was programmed to return to a straight shape when heated and was sewed onto a thick felt fabric. The felt material was used to hold the nitinol wire in place, protect the skin, and produce a warm fuzzy feeling when the nitinol wire was heated. The elastic connections were tested in different shapes, from thinner threads to wider bands. When the wire is heated, it forces the U-shape to open, putting the felt material in closer contact with the skin and creating a feeling of slight pressure. Because of the tension of the elastic band, the material is forced to return to its initial U-shape.

We preferred the second approach, as it required less power to achieve the transformation, allowed more flexibility in the design, and produced a better user experience because of the more ubiquitous feeling of warmth. This second approach also presented a few challenges. The transition from one shape to another occurred much more slowly than in the first approach, in which we used the spring, and was not easy to control. The speed of the transformation limited the range of pace of haptic action we could use. Because of the difficulty of material behavior control, the prototypes underwent many iterations in order to arrive at the desired capacity for speed transformation, feeling, and amount of pressure.

Following the second design approach, we arrived at a final design using synthetic felt fabric for the U-shape and a wide elastic band for the connection material. The synthetic felt material was stiffer and lighter than wool felt fabrics and worked better for the desired material transformation. The elastic band had more strength to pull the material back into shape than the thinner bands and provided greater coverage of the forearm. We chose to use a double layer of fabric material and sandwiched the nitinol wire in-between, protecting the wearer from accidentally touching the

FIG I. 3
Final prototype of the Affective Sleeve made from felt fabric, nitinol wire and elastic bands. Top view

FIG I. 4
Final prototype of the Affective Sleeve made from felt fabric, nitinol wire and elastic bands. Side views

wires and distributing the heat more uniformly. We arrived at a modular design of a sleeve composed of six cuffs, where each cuff is composed of the fabric-made U-shape, a detachable elastic band, and two nitinol wires sandwiched in-between the two layers of fabric [FIG I. 3-6].

We decided to make a modular sleeve that could fit any body shape. The cuffs are designed as autonomous rings of fabric and elastic; the connectivity of the wires creates an internal common wired structure that will not allow the cuffs to detach from each other completely but will permit micro adjustments for better fit. The cuff shape is curved, forming a cone once folded around the arm. The cuffs are designed in different sizes to follow the natural widening of the shape of the forearm [FIG I. 4]. The conic shape of the sleeve allows each cuff to be slightly inserted into the next slightly bigger one, for full coverage and flexible adjustment. To further customize the sleeve based on the user's body, we made elastic bands of different lengths. The variously sized bands can snap onto the fabric U-shape to adjust the cuff's diameter.

The second reason we wanted a modular sleeve is that the design permits each cuff to be controlled independently, allowing the programmer/design to implement any number of patterns and paces of haptic action. Moreover, the haptic action produced is more effective when each cuff operates independently, as the actuation is faster and better controlled; the heat and pressure remain steady in each cuff, producing a serial action that begins at the wrist and ends at the elbow. We felt that serial haptic action would create a sense of rhythm and greater awareness of action in the wearer, leading to better synchronization between the rhythms of the body and the material, regulating the breathing function accordingly.

The idea of the sequential activation of the cuffs was inspired by meditation practices where the focus of a practitioner's attention is transferred from one location of the body to another in sequential manner, eventually "scanning" the entire body. In this body-scanning meditation, it is a common practice that the practitioner starts the scanning process from the fingers or toes and slowly moves attention towards the center of the body and head.[1] The sequential actuation of the cuffs also allows areas of the body to recover from the warmth and pressure before responding again to the haptic action [FIG I. 7].

The cycle of haptic action of the sleeve was programmed according to a full cycle of breathing, calculated by measuring the inhalation and

1 A script of the body-scanning meditation practice can be access as audio file at this link from UC San Diego Health: https://health.ucsd.edu/av/mindfulness/45MinBodyScan07mono.mp3 Accessed: 29 April 2021

FIG I. 3
Internal structure of the final prototype made of two parallel placed nitinol wires per cuff. The parallel nitinol wires change shape when current passes through returing to a preprogrammed flat shape.

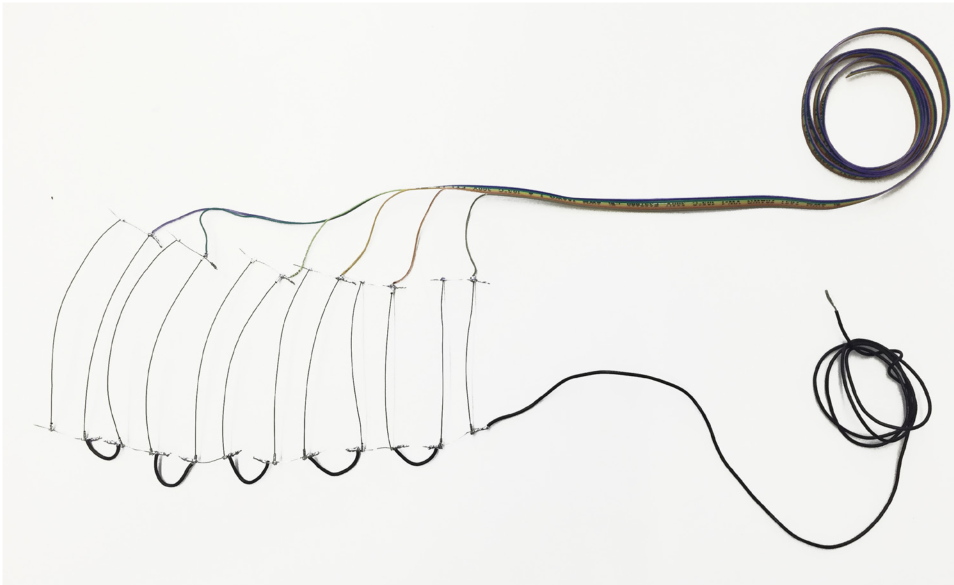


FIG I. 4
Final prototype of the Affective Sleeve made from felt fabric, nitinol wire and elastic bands.Top view when cuffs are unfastened.

FIG I. 5
Final prototype of the Affective Sleeve made from felt fabric, nitinol wire and elastic bands. perspective view when cuffs are fastened.

exhalation time minus one second, to allow for switching from one state and other. If T is the time in seconds corresponding to a full cycle of breathing (duration of inhalation and exhalation), the current passing through each cuff for a duration of T-1 sec [FIG I. 8]. Because the material does not transform immediately, the felt pressure approximates the duration of a half cycle, thus mimicking through the material actuation the inhaling and exhaling functions. This behavior was intentional, as we wanted the duration of the felt pressure-state to match the duration of inhalation and the non-pressure duration to match the duration of the exhalation. Because inhalation activates the sympathetic system, and exhalation activates the parasympathetic system [see chapter 2.3.1a], we thought that a correspondence between felt pressure (aroused state) and no felt pressure (relaxed state) would achieve the best synchronization.[1]

The nitinol wire used in the final prototype had a diameter of 0.5 mm. In the design iterations, different diameter sizes were tested, as these had an impact on the required temperature for transformation and on the material's elasticity and tension. After testing, we found that the 0.5 mm provided the optimum results regarding the design and transformation we were aiming for. To transform each cuff from a U-shape to a wider shape producing feelings of warmth and pressure, the wires needed to be heated up to temperatures above 45 degrees Celsius.[2] With the chosen felt fabric materials, the surface temperature of the sleeve ranged from 26 degrees Celsius, when no current passed through the cuffs, to 38 degrees Celsius, when current passed through the cuffs and the temperature reached its peak. A temperature of 38 ° C is comparable to that of a warm bath or a muscle-relaxing heating pad. The felt pressure is comparable to that of a light human touch [FIG I. 7].

---

1 Although a synchronization between pressure and inhalation, and no pressure and exhalation was desired, we did not test for this parameter and thus it is not possible to know if the synchronization occurred.

2 To program the shape to return to the desired form, the nitinol needs to be heated up in a furnace in temperatures above 400-500 degrees Celsius. This procedure only needs to take place once, unless the shape needs to be re-programmed.

FIG I. 6
A cuff of the Affective Sleeve prototype during shape change. Left: When no current passes through the wires. Right: When current passes through the wires producing warmth and light touch sensation due to shape change.

FIG I. 7
Each cuff of the affective sleeve was programmed to activate in sequence in direction from the cuff towards the elbow. The activation time was programmed based on each indiviudual's breathing cycle.

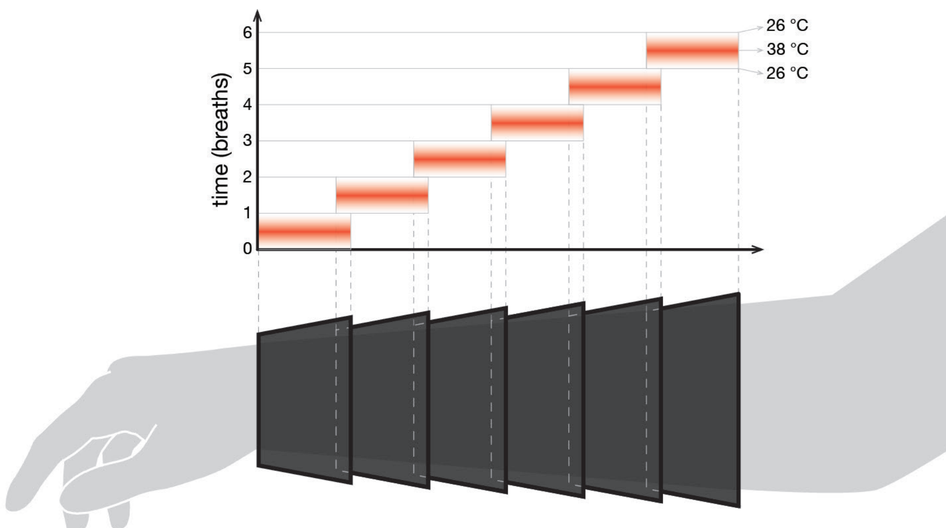
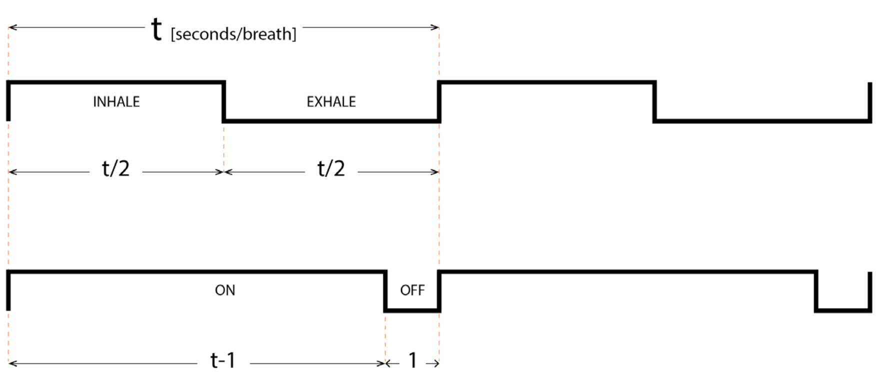


FIG I. 8
The activation of each cuff of the Affective Sleeve was programmed based on each individual's breathing cycle. Current passed through each cuff for a full beathing cycle minus a second. Slight pressure was felt for approximately half cycle.



3.1.3b EXPERIMENTAL METHOD AND HYPOTHESIS

Our broader goal was to test whether the affective sleeve could act as a material-mediated emotion self-regulation system. To receive answers towards this broader goal, we decided to focus on the impact of the affective sleeve on anxiety levels, testing whether it can help reduce the wearer's psychophysiological symptoms of stress. We aimed to show that the pace of the haptic action of the sleeve has an impact on one's state of feeling either calm or anxious. Given the tendency we have to synchronize our bodily rhythms with the rhythms of the environment through entrainment processes, and the evidence provided by prior studies on the impact of rhythmic sensory stimuli on our emotional state, we formulated the hypothesis that a slow and fast pace of haptic action of the Affective Sleeve can decrease and increase, respectively, participants' psychophysiological symptoms of stress.

During the stress-inducing task, we expected that the breathing rate of the participants would become faster if the haptic action of the sleeve is faster than their relaxed breathing rate, and slower if the haptic action of the sleeve is equal to their relaxed breathing rate. We expected that during the stress-inducing task participants breathing rate would be faster than in the relaxed state because breathing tends to become faster and shallower in stressed states. We hoped that the sleeve could help regulate breathing, increasing or decreasing the breathing rate according to the pace of haptic action of the sleeve. As slow breathing is linked to the activation of the parasympathetic system, we expected that slowing the breathing rate would produce feelings of calmness, thus reducing the participants' psychophysiological symptoms of stress.

Regulating breathing may lead to regulation of other functions such as heart activity as a result of intrapersonal entrainment processes like respiratory sinus arrhythmia [see section 2.3.1a], although the connection between respiratory and heart activity was not tested in the study. In addition to measurements of participants' breathing rate (BR) throughout the study, we also measured participants' electrodermal activity (EDA). EDA serves as a non-invasive measure of the sympathetic nervous system's "fight or flight" response. EDA levels are typically higher in situations of high arousal, such as states of excitement or stress, than they are in situations of low arousal, such as calm or tired states. EDA levels do not explicitly indicate positive or negative affective states, but they usually provide a good indication of stress in the context of a stress-inducing task. Based on our hypothesis, we expected that during the stress-inducing task, participants wearing a sleeve with slow haptic action would exhibit lower increases in EDA level than participants wearing a sleeve with fast haptic action.

To test our hypothesis, we randomized participants into three groups: the Slow, Fast, and Control groups. Each group participated in the stress-inducing task of taking a quiz while wearing the affective sleeve. In the Slow group, the affective sleeve was programmed to produce haptic action (slight warmth and pressure) at a pace equal to each participant's relaxed breathing rate. In the Fast group, the affective sleeve was programmed to produce haptic action faster than each participant's relaxed breathing rate. In the Control group, the affective sleeve was programmed to produce no haptic action. We expected participants in the Fast group to exhibit higher increases in breathing rate and electrodermal activity than participants in the Slow and Control groups. We also expected participants in the Slow group to exhibit lower increases in breathing rate and electrodermal activity than participants in the Fast and Control groups.

We recruited 18 participants, all students at the Massachusetts Institute of Technology. Out of the 18 participants, 16 were in graduate programs and two were undergraduates; 15 were students in the school of Architecture and Planning, 1 was a student in the Mathematics department, one in Bio-electrical Engineering, and 1 in Materials Science. For the stress-inducing task we decided to use a quiz, since this would simulate an exam setup that students were familiar with. We wanted the type of the quiz to be accessible to all participants in terms of the required skills, so the stress-inducing factor would be the time needed to complete the quiz, not the knowledge needed. Given that many of the participants were from the Architecture department, we decided to create a quiz of spatial cognition from standardized tests that would include questions about spatial reasoning.

3.1.3c EXPERIMENTAL PROCEDURE

The controlled study was approved by the Committee on the Use of Humans as Experimental Subjects (COUHES), established to act as the Institutional Review Board (IRB) for the Massachusetts Institute of Technology. Participants were recruited through email advertisements and informed that they would be compensated with a $10 gift card for their participation and additional $50 if they achieved one of the two highest scores in the spatial cognition quiz. We added the extra compensation for the quiz winners to make the task more competitive and motivate participants to demonstrate good performance. We decided to withhold the true aim of the controlled study because if the participants knew we were measuring the stress levels, they might consciously manipulate their physiology or behavior. Instead, participants were told in the email advertisement and consent form they signed that the study would test the impact of a novel wearable technology on cognitive performance.

For the measurement of EDA levels, we chose to use the Empatica E4 wristband [reference]. With the E4 sensor we used the extension that allows the use of two adhesive electrodes on the fingers to ensure good quality of the measurements. We placed the electrodes on the participants' index and middle fingers on the intermediate phalanges, to allow the fingers to be used for writing or typing when needed. Because we asked the participants to wear the sleeve on their non-dominant hand, so as to avoid muscle activity interfering with the results, we asked them to wear the EDA wristband on their dominant hand. We were aware that this decision allowed for artifacts due to movement to affect measurements. However, wearing the EDA sensor on the same arm as the sleeve would more significantly affect the results: the warmth produced by the sleeve could directly affect the sweat levels of the skin that determine the levels of skin conductance. For the measurement of breathing activity (BR), we chose to use the Zephyr Biopatch sensor, which is worn on the chest using adhesive electrodes [reference].

The procedure of the controlled study consisted of five phases: (1) signing the consent form (2) establishing baseline conditions, (3) doing the habituation task, (4) doing the performance task, and (5) completing qualitative surveys and debriefing [FIG I. 9-10]. Participants wore the sleeve and physiology sensors for the entire duration of the baseline phase (phase 2), the habituation task (phase 3), and performance task (phase 4). The participants were asked to remove the sensors and sleeve after they had completed the performance task. The sleeve's haptic action was programmed relative to the average relaxed-state breathing rate of individual participants: in the Slow group, the haptic action was equal to the average relaxed-stated breathing rate; in the Fast group, the haptic

FIG I. 9
Each participant was wearing sensors to measure their breathing and electrodermal activity and the affective sleeve. The procedure included 15 mins of baseline measurements, 10 minutes of habituation (practice quiz) and 15 minutes of performance (scored quiz)

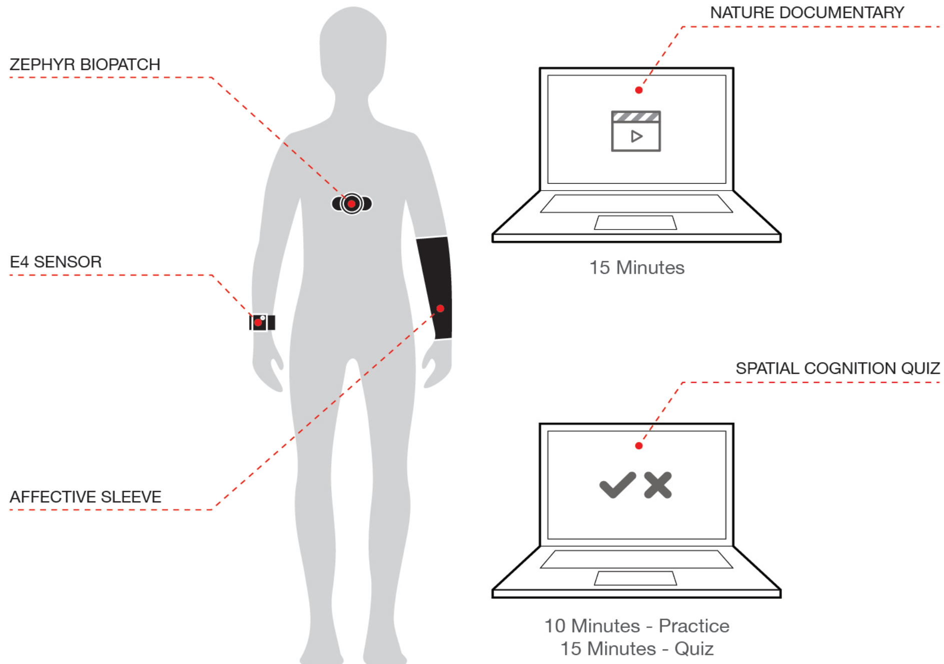
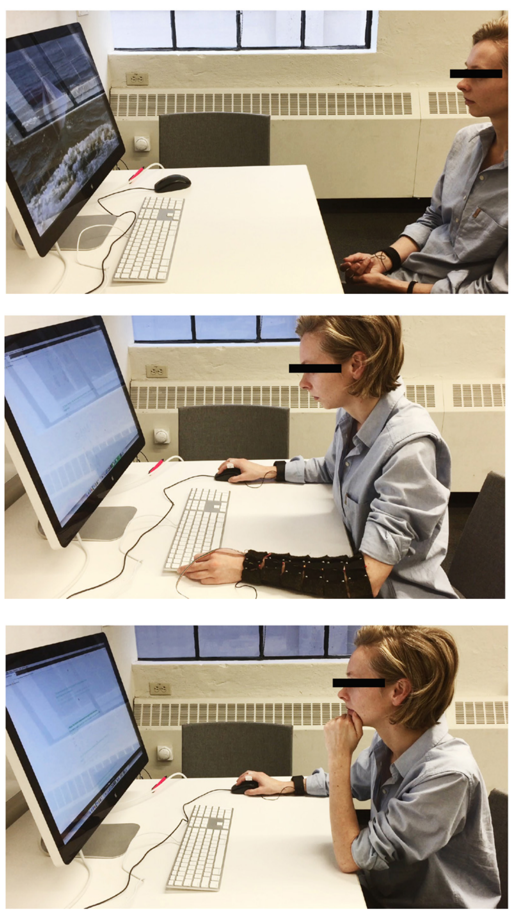


FIG I. 10
A partcipant in the experiment during the baseline phase while watching a nature documentary to relax (top); the same participant during the habituation and perfomanced tasks while taking the quiz (middle); the same participant while filling out the survey (bottom)



action was 25% faster than the average relaxed-stated breathing rate; in the Control group, there was no haptic action.

Participants were tested one at a time and did not interact with other participants during the study. The study took place in a multifunctional room at MIT equipped with an office desk and chair, where each participant remained throughout the process. The experimenters interacted with the participants between each phase of the procedure to help them put on or remove the sensors and/or sleeve, and to set up the computer for the habituation and performance tasks. At least one of the two experimenters remained in the room for the whole duration of the study to minimize any potential risks or complications. Between the interactions with the participant, the experimenters sat in a distant location in the room and did not engage in any activity that might distract the participants.

Establishing baseline conditions. After signing the consent form and being informed about the study procedure, the participants proceeded to the room where the control study was taking place. Participants were given the EDA and BR sensors to wear and were asked to watch a nature documentary for 15 minutes. We chose this type of activity to encourage relaxation in order to obtain relaxed-stated baseline measurements. We worried that simply asking the participants to sit and relax, without being engaged in any activity, would be ineffective. To calculate the average breathing rate of the participants, we used a phone application that allowed us to have a real-time streaming of the participants' BR data while they were watching the documentary. The average breathing rate for each participant in this phase was used to determine the values needed to program the sleeve's haptic action. The measurements of the EDA and BR sensors from this phase were used to account for variations in participants' physiology, establishing a baseline for each participant for the statistical analysis.

Habituation task. After the phase of baseline measurements, the experimenters interacted with the participants to help them put on the sleeve and to adjust it to their forearm for optimum fit. The participants continued to sit on their chairs while the experimenter set up the computer for the habituation task. The habituation task lasted 10 minutes and the goal was to accustom participants to the feeling of the sleeve, minimizing arousal due to the novelty of the intervention. Also, the habituation task allowed participants to get accustomed to the type of the quiz and give them the opportunity to ask questions to the experimenters. The habituation task was a sample of the quiz that would serve as the performance task and consisted of multiple-choice spatial reasoning questions. The participants were informed that the practice quiz would not count towards their final score.

Performance task. After the habituation task, the experimenters interacted with the participants to respond to any questions they had and set up the performance task. The performance task consisted of a quiz with multiple-choice spatial reasoning questions, some previewed in the practice test of the habituation task. In order to elicit a feeling of stress in the participants, we intentionally designed the quiz to be impossible to complete within the given 15-minute timespan. The average score among all participants was 36%, the median 33%, the highest 57%, and the lowest 18%. The sources of the spatial reasoning multiple choice questions were the test-books by Wiesen [2015] and McMunn [2014].

Qualitative surveys and debriefing. After the performance task, the experimenters interacted with the participants to help them remove the affective sleeve and sensors and distributed qualitative surveys to be filled out manually. As part of the surveys, the participants also filled out the Perceived Stress Scale (PSS) questionnaire, which has been scientifically verified and widely used. We used the PSS as a post-study mental health screening method that would allow us to evaluate whether stress responses during the study were due to other circumstances in the participant's life. We decided to not ask participants to fill out the PSS questionnaire at the beginning of the study as this could potentially reveal the true aim of the study. Finally, the participants were given a post-study debriefing document that informed them about the true aim of the study. Participants were encouraged to ask any questions regarding the goals or process of the study and were told not to disclose the aim of the study to other individuals who might possibly volunteer as study participants.

3.1.4. RESULTS

3.1.4.a PHYSIOLOGICAL DATA ANALYSIS

Data were processed identically for all participants. For each participant, separately for the EDA values and BR values, we calculated the mean value and standard deviation for the baseline, habituation, and performance phases of the study. We excluded any data lying outside two standard deviations from the mean values. The intent of this exclusion was to reduce distortion caused by noise in the data samples. We then scaled (stretched) each segment of data to fit within a 15-minute, 10-minute, and 15-minute window corresponding to the baseline, practice, and performance phases, respectively, to ensure that each phase of the experiment aligned on the same timescale for all participants.[1] After removing the noise, we normalized the data per participant (maximum over the whole session = 1, minimum over the whole session = 0) to eliminate any difference in individual ranges). We then calculated the difference between the mean value of the performance phase and mean value of the baseline phase for each of the participants. Using those difference values we then calculated the average difference from the baseline phase to the performance phase for each of the groups as a whole.

We chose to use the Kruskall-Wallis test to evaluate the statistical significance of the results, as we did not have a normal distribution of the data. The lack of normal distribution was due to the limited number of participants. Results from the EDA data demonstrated that the average change in EDA in the Slow group was 0.095 μS less than the Fast Group and 0.078 μS less than the Control Group. The finding that the average increase in EDA values from baseline to performance tasks was less in the Slow group when compared to the Fast and Control groups was in line with our expectations, as was the fact that the value of difference compared to the Fast group was greater than the value of difference compared to the Control group. However the difference was not statistically significant (p-value > 0.10) [FIG I. 11].

Comparisons of the average change in breathing rates (BR) from the mean values of the baseline phase to the mean values of the performance task phase, demonstrated that participants in the Slow group breathed 0.021 bpm faster than the Control Group and 0.142 bpm slower than the Fast Group. These results differed from our expectations in that we expected participants in the Slow group to have a smaller increase in their BR than participants in the Control group. As expected, the increase

1 There were small differences in the duration of the actual measurements (not more than 60 sec) due to the manual tagging of start and ending of each phase.

in BR in the Slow group was indeed smaller than the increase in BR in the Fast group. When comparing the results of the Fast group to those of the Control group, the increase in BR is statistically significant ($p = 0.0105$). In support of our hypothesis, this result suggests that a fast rate of haptic action of the sleeve correlates positively to the breathing rate [FIG 1. 12].

To gain insights into overall trends of the values for each group, we used a fourth-degree polynomial on the mean values of all three main phases of the procedure. The graphs with the fourth-degree polynomial show overall trends toward higher values, indicative of the stressed-induced reaction to the quiz. The vertical lines in the diagrams indicate the changes between the baseline, switch time, habituation task, switch time, and performance task -- where switch time is the time not counted towards the final comparison measurements, when the experimenters interacted with the participants to set up the next phase [FIG I. 13-14]. Finally, regarding the Perceived Stress Scale (PSS) questionnaire [Cohen, S. 1994; 1983], the mean for our participants (16.27) was much higher than the mean provided in the PSS (12.1 for males, 13.7 for females), showing that the study participants were more stressed than "average."

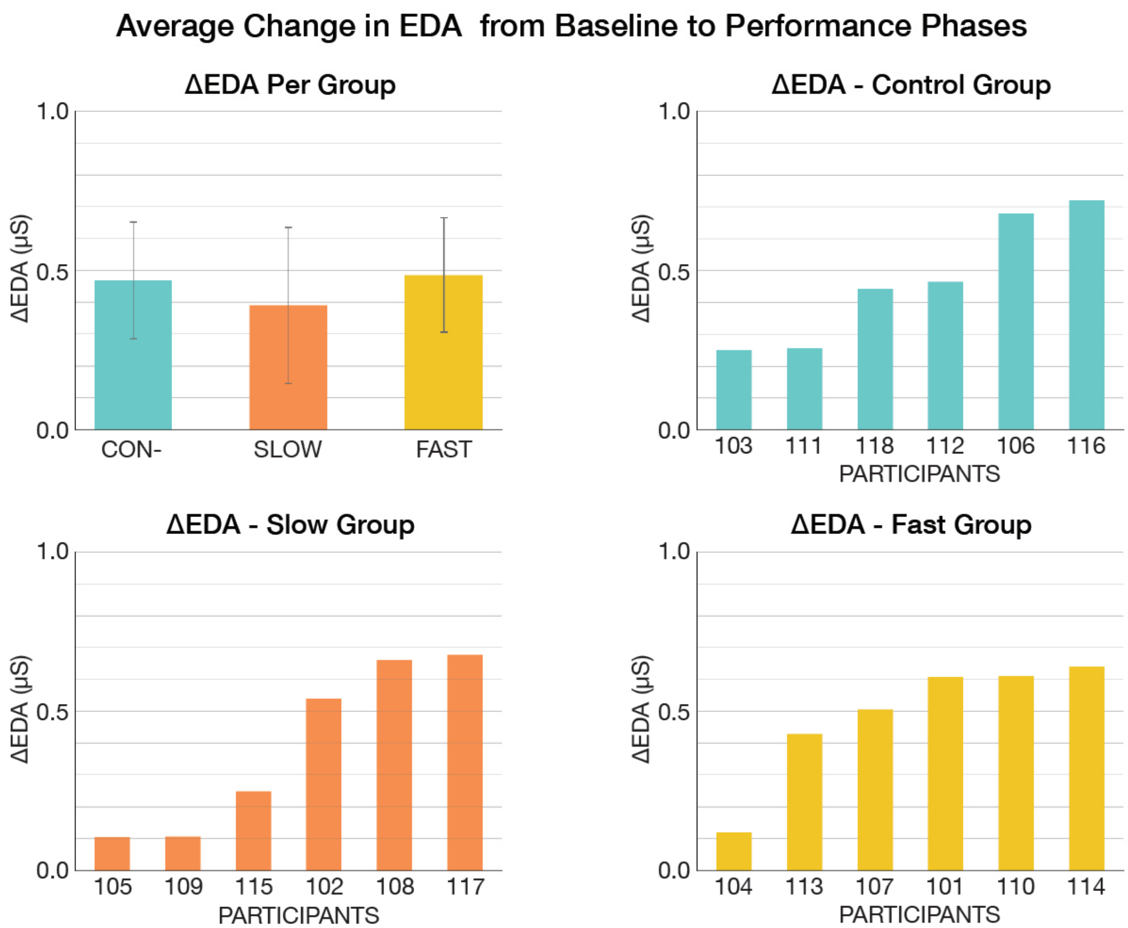


FIG I. 11
Bar graphs demostrating the average change in electrodermal activity (EDA) from Baseline to Perfomance phase for the Control, Slow, and Fast groups and for each individual per group.

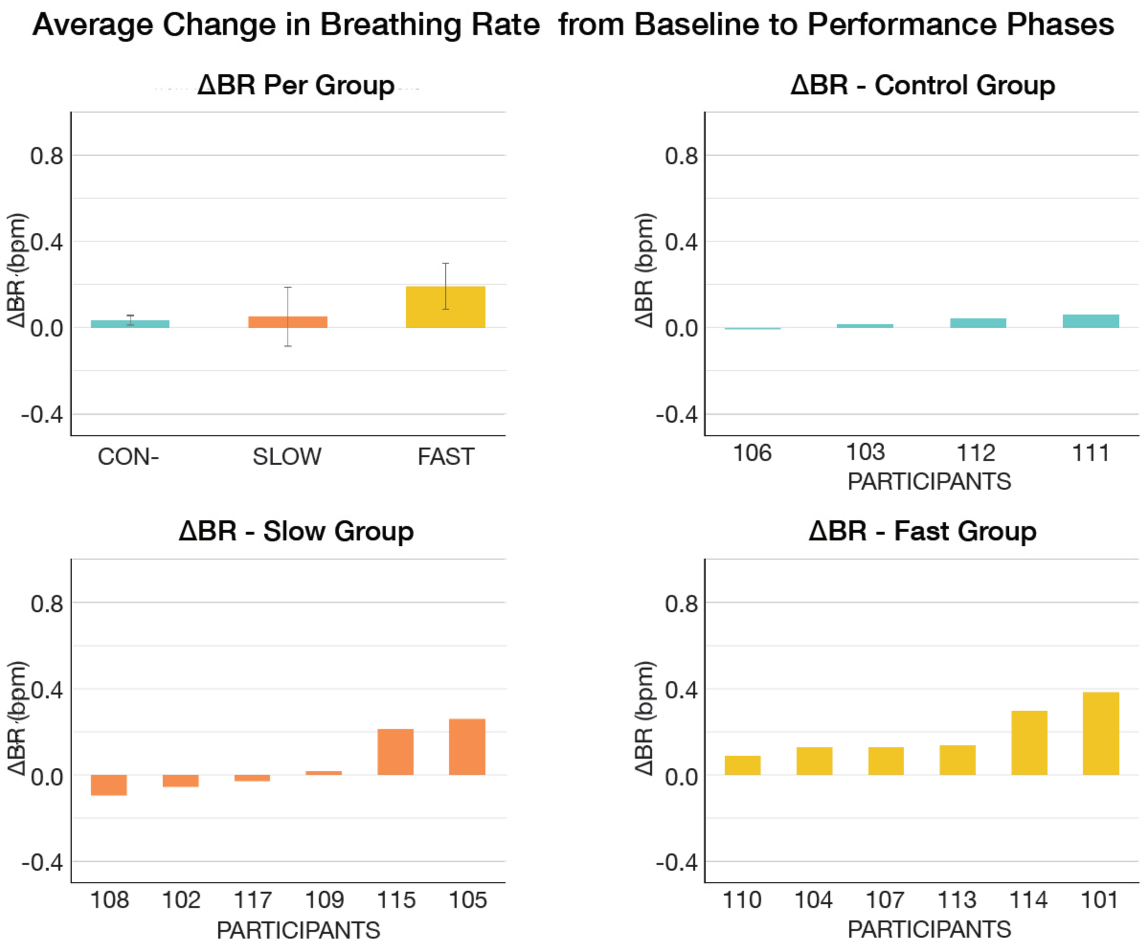


FIG I. 12
Bar graphs demostrating the average change in breathing rate (BR) from Baseline to Perfomance phase for the Control, Slow, and Fast groups and for each individual participant per group.

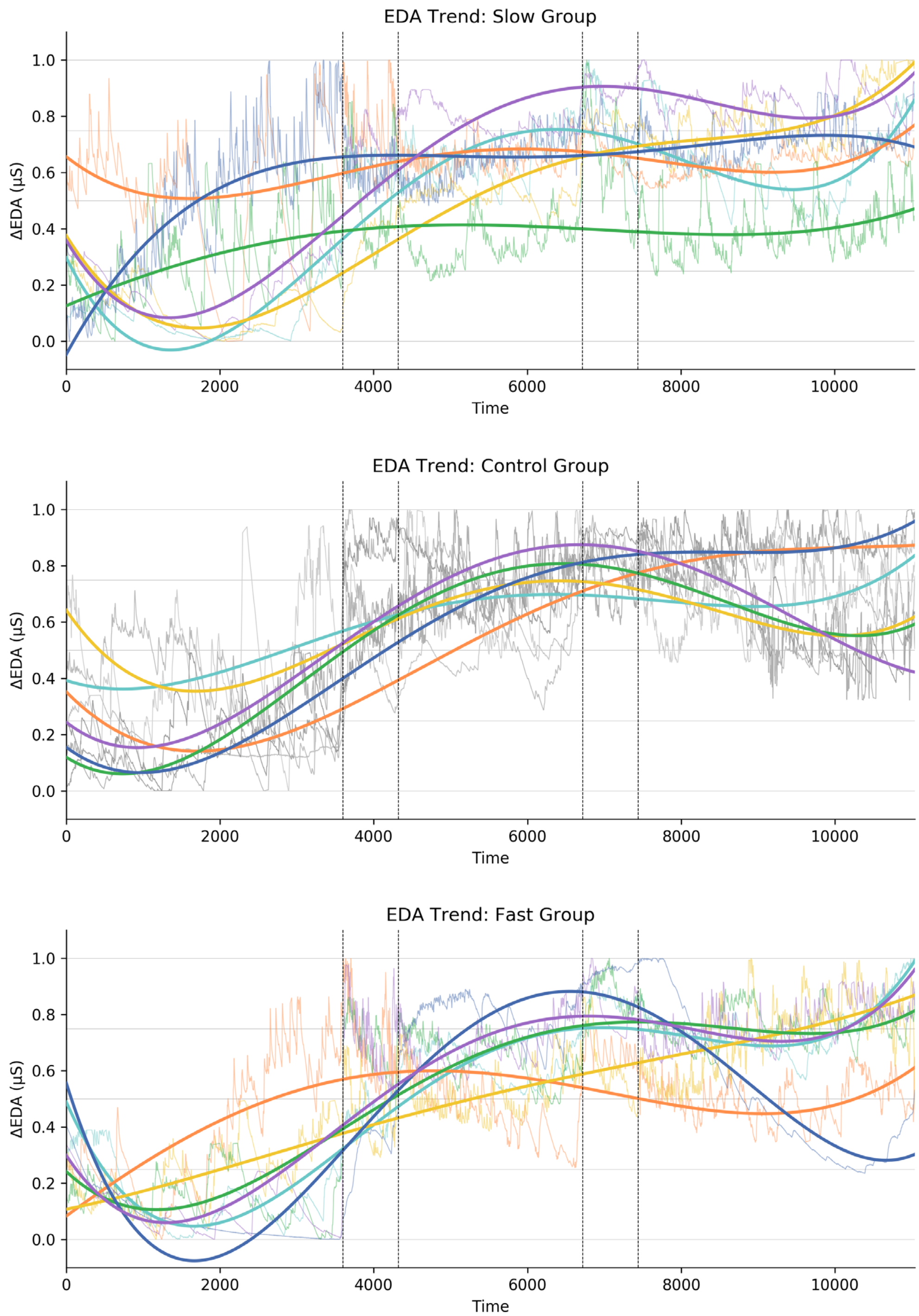


FIG I. 13
Overall electrodermal activity (EDA) trends for each group using a fourth-degree polynomial on the mean values of all three main phases of the procedure (baseline, habituation, performance). The vertical lines iindicate the “switch time” between the three phases.

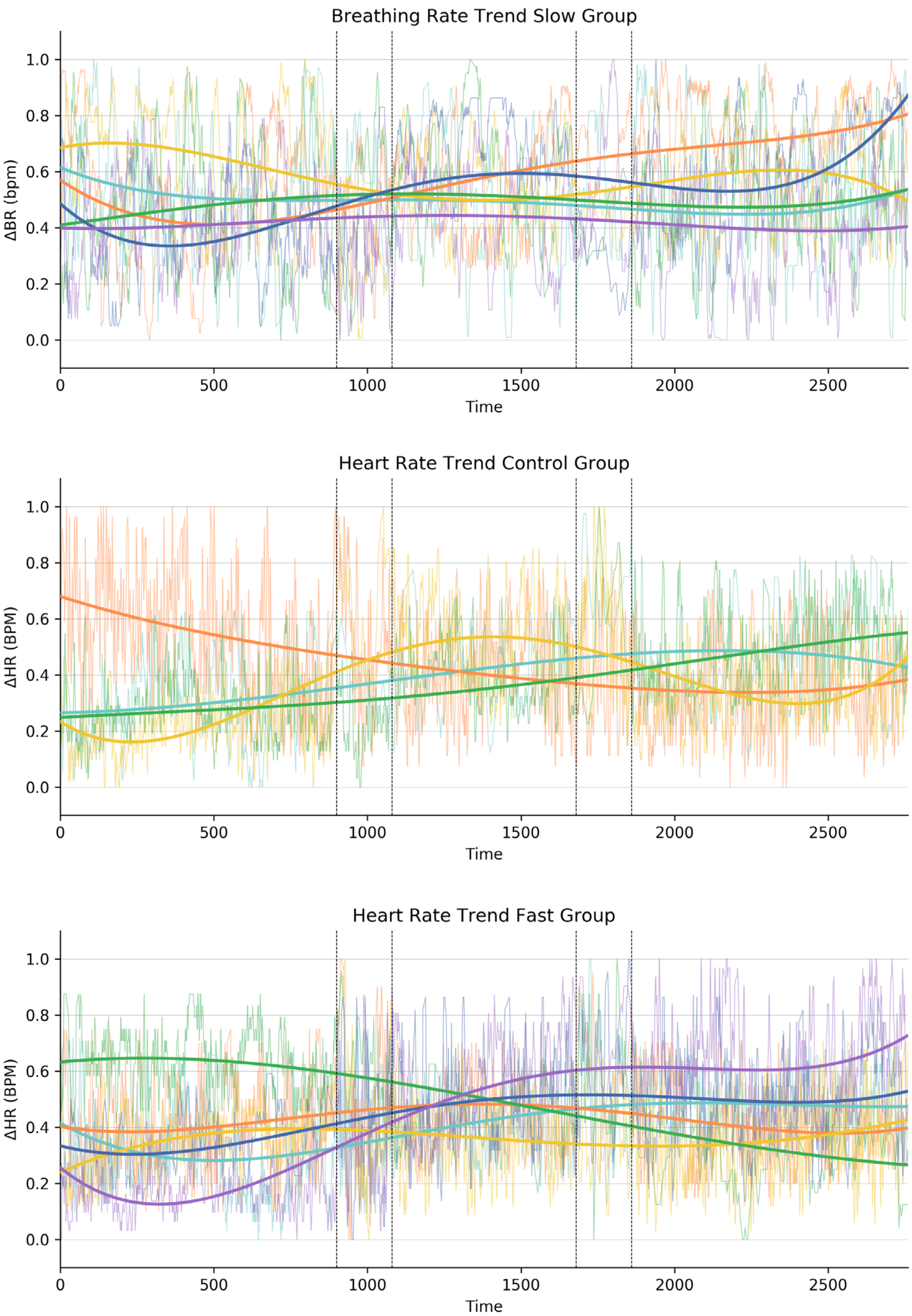


FIG I. 14
Overall electrodermal activity (EDA) trends for each group using a fourth-degree polynomial on the mean values of all three main phases of the procedure (baseline, habituation, performance). The vertical lines iindicate the “switch time” between the three phases.

3.1.4b SELF-REPORTED DATA ANALYSIS

After the performance task, participants were given a questionnaire we designed. The aim of the questionnaire was to evaluate participants' experience of wearing the sleeve and to describe the sensations they felt. We were interested to know how the sleeve affected participants' perception of calmness and we wanted feedback regarding the specific sleeve design and type of haptic action. The questionnaire included 13 questions. Out of the 13 questions, 11 had a multiple-choice format, providing a scale of 0 to 4—0 indicating negative, 2 neutral, and 4 positive. The remaining two out of the 13 questions prompted written feedback. The questions that are most relevant to our hypothesis are discussed below. The full list of questions along with pie charts of the results is included in the appendix.

When asked about the comfort of the affective sleeve, 50% of the Control Group reported as follows: 16.6% reported they were very comfortable; 16.67% neutral; 33.33% a bit uncomfortable; and 16.67% very uncomfortable. In the Slow group 50% of the participants reported that they felt very comfortable; the remaining 50% reported that they felt a bit comfortable. In the Fast Group, 66.6% of the participants reported that they felt neutral comfort 16.67% a bit comfortable; 16.67% very comfortable. These results are aligned with our expectations as they indicate that the pace of the sleeve had a negative correlation with participants' perception of comfort: when the pace matched the relaxed breathing rate, it was perceived as more comfortable. When the pace was faster than the relaxed breathing rate, the sleeve was perceived as more uncomfortable than it was under the other conditions [FIG I. 15].

When asked about the effect of warmth produced by the sleeve, 66.6% of the participants in the Control Group reported that warmth felt neutral and only 33.3% reported it felt a bit calming. In the Slow Group, 83.3% of the participants reported that the warmth felt either a bit calming or very calming (66.67% a bit calming; 16.67% very calming) and 16.6% reported it felt neutral. Of the participants in the Fast Group, 50% reported that the warmth felt neutral and 50% reported it felt either a bit calming or very calming (33.33% a bit calming; 16.67% very calming). These results support our hypothesis, as they suggest a positive correlation between a slow pace of warmth stimuli and perception of calmness: participants in the Slow Group perceived the warmth of the sleeve as more calming than did participants in the Fast or Control Groups. This suggests that pace of produced warmth matching the relaxed breathing rate promotes relaxation, whereas a pace faster than the relaxed breathing rate may not promote relaxation [FIG I. 16].

FIG I. 15
Participants' responses to the question "Regarding confort, wearing the Affective Sleeve felt..."

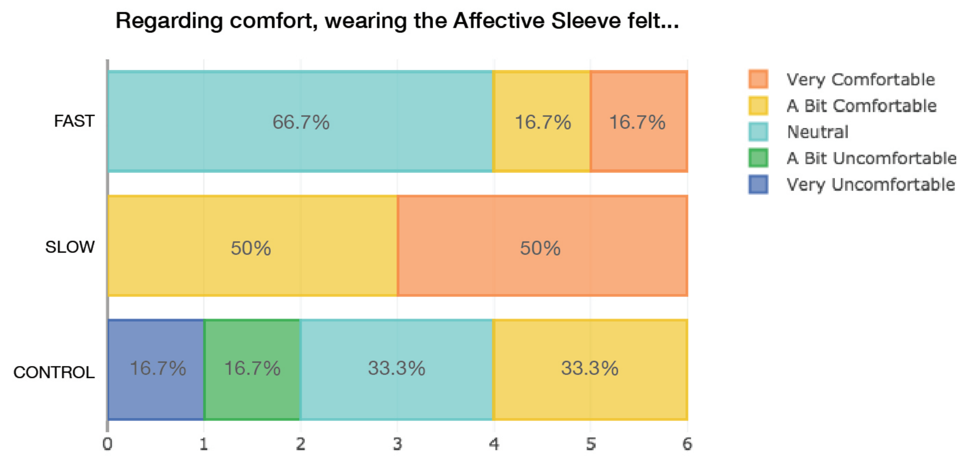


FIG I. 16
Participants' responses to the question "Was the sleeve's warmth calming?"

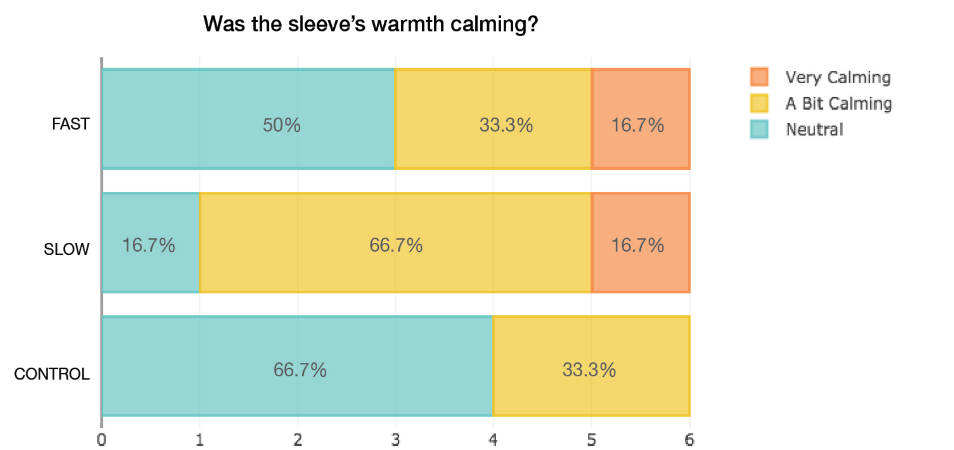
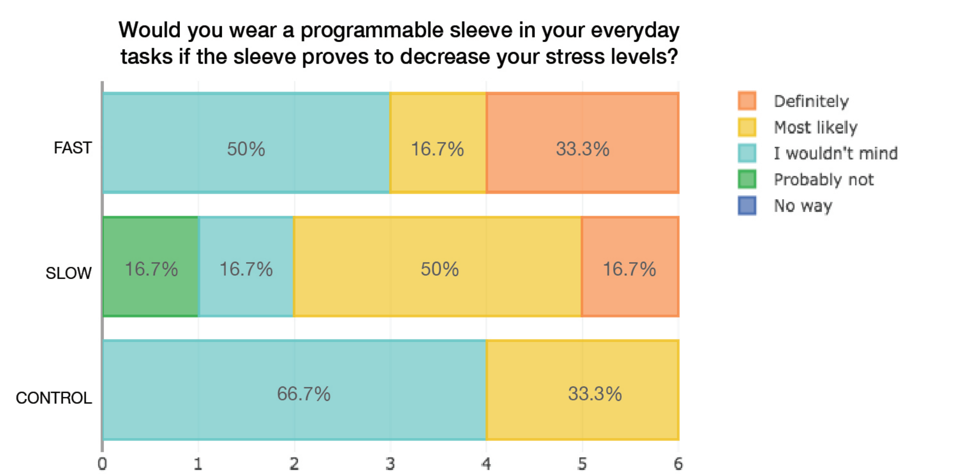


FIG I. 17
Participants' responses to the question "Would you wear a programmable sleeve in your everyday tasks if the sleeve proves to decrease your stress levels?"



To understand whether or not the haptic action of the sleeve interfere[1]d with participants' performance, we asked participants if they thought that the sleeve was distracting or if they thought that it helped them focus. In the Control group, 66.67% of the participants responded that it neither helped them focus nor it felt distracting (16.67% a bit distracting; 16.67% helped me focus a lot); in the Slow group 66.67% of the participants gave the same neutral response (33.33% helped me focus a bit); and in the Fast group 66.67% of the participants responded neutrally (33.33% it was a bit distracting). In these responses it is interesting to observe that most participants gave a neutral response and that, aligned with our expectations, from those that didn't, the ones who reported that the sleeve was distracting were in the Fast group, and the ones who reported that it helped them focus where in the Slow group.[2]

Participants were also asked if they would wear the Affective Sleeve in their everyday lives if it were proven to decrease stress levels. We wanted to see if the experience each group had of the sleeve would affect their decision to wear it. To this question, 66.6% of the participants in the Control group responded, "I wouldn't mind" (33.3% most likely); 66.6% of the participants in the Slow Group responded either "most likely" or "definitely" (50% most likely; 16.6% definitely; 16.67% probably not); and 50% of the participants of the Fast Group responded "most likely" or "definitely" (50% I wouldn't mind; 16.6% most likely; 33.33% definitely). Compared to the Fast and Control Groups, participants in the Slow and Group were more apt to wear to the sleeve in their everyday lives. This is interesting as it shows that overall the experience of haptic action had a positive impact on the wearers' decision to wear the sleeve [FIG I. 17].

The results of the questions we reviewed are aligned with our expectations that a slower pace of haptic action would create a more pleasant and calming experience than a faster pace of haptic action. The written feedback participants gave in the form also seems to support our hypothesis. To the question "How would you describe the sensation of wearing the programmable sleeve?" six out of six of the participants in the Slow group responded that it was pleasant and comforting, although they used different phrases to describe the feeling, sometimes very creative. For example, one of the participants of the Slow group wrote that the sensation of wearing the sleeve "felt like a cat was laying against

---

1 This question also aimed at masking the true aim of the study, as participants were told that we would be testing how the sleeve affects their performance, and not their stress levels.

2 The mean scores of the quiz for each of the groups did not reflect a difference in the actual quiz performance: the Control Group averaged 32%, the Slow Group averaged 34% and the Fast Group averaged 34%.

[her] arm. Some warmth and movement." It is very interesting that the participant made an analogy with the feeling of touch from another being, as this was one of our intentions in the design of the sleeve: to simulate actual touch through slight pressure and warmth.

To the same question, "How would you describe the sensation of wearing the programmable sleeve?" only two out of the six participants of the Fast group described the experience as pleasant. One of the participants gave a rather neutral response, saying that she was too focused on the test to notice, while acknowledging the feelings of slight warmth and pressure. The rest of the participants gave a rather negative or mixed description, reporting that they found the sleeve to be a bit distracting. For example, one of the participants wrote, "The warmth it was emitting was very comforting, but I found the motion to be a bit distracting," while another one wrote, "It seemed to add a little pressure on my arm; I would tighten it less." Although most unpleasant feelings were associated with the feeling of pressure, some found the pressure pleasant. One participant in the Fast group wrote that it felt like "a tight-ish blanket for the arm. A cozy-ish feeling."

To the same question, "How would you describe the sensation of wearing the programmable sleeve?" the participants of the Control group responded as expected. Five out of the six participants reported that they either did not feel any of those sensations or did not notice them, saying, for example: "It just felt like I was wearing a long-sleeve shirt. I didn't notice the vibration or the heating," or "I did not feel anything other than the fabric on my skin." Only one out of the six acknowledged the haptic action by writing that it was "comforting" but "not too noticeable." We argue that we should understand this report, not only as a placebo effect but also as the result of the experience of wearing a sleeve: that the sleeve feels a little warm even when not heated. Another participant reported: "I am not sure if I noticed it as much as I was supposed to, maybe because I was paying attention to the test instead. Mainly I noticed when the heat decreased."

From the oral interviews, we found that some of the participants either did not feel the movement of the warmth along the arm (produced by the sequential haptic action of the cuffs) or felt it slightly but were unable to specify the direction of movement. Also, some participants reported an overall sensation of warmth and pressure but were unable to specify the source of the heat. Others reported local sensations of warmth and pressure, but at different positions along the forearm: some felt it towards the wrist, and others towards the elbow. The inability of participants to identify the source and direction of the warmth may be due to the fact that the material remained warm for a short period after the current had passed through it. Another reason for participants not noticing or differentiating the sensation might be that the pressure was not strong enough to elicit a reaction or that they were focused on the activity of taking a quiz.

Curiously, two Slow group participants reported that although they felt the warmth, they did not notice any pressure in the sleeve, while two participants of the Fast Group that experienced the pressure stimulus noted that they were not very aware of the warmth. This observation raises the question of whether the pace of the haptic action affects which sensory stimulus is perceived as dominant. In this case, we conjecture that the fast pace makes pressure the dominant stimulus and the slow pace makes warmth dominant. To draw further conclusions about this relationship, we also need to take into account the fact that the cuffs in the fast action condition do not reach the same temperature as the cuffs in the slow action condition because they are activated (heated) for a shorter duration of time.

3.1.5. CONCLUSIONS

The results of the quantitative analysis demonstrated a statistically significant positive correlation between the pace of haptic action and the participants' breathing rate. This result is aligned with our hypothesis that a haptic action higher than the relaxed breathing rate can affect our physiology by increasing our breathing rate. Aligned with our expectations, the average increase from the baseline phase to the performance task was higher in the participants in the Fast group than in those in the Slow group, even though the number of participants was not large enough to prove this difference statistically significant. We hoped to show that a pace of haptic action equal to relaxed breathing rate could reduce the wearer's breathing rate under stress conditions. However, the fact that the average BR increase from baseline to the performance task was greater in the Slow group than the Control group did not align with our expectations. It is possible that such a correlation was not demonstrated because the novelty of the intervention caused additional physiological arousal.

The results of the EDA measurements were also not statistically significant due to the small number of participants, but the results of the comparisons between the groups hint at the expected direction: the average increase in EDA levels from baseline to performance phase in the Fast group was higher than in the Control group, and the average increase in EDA levels from baseline to performance phase in the Slow group was lower than in the Control group. A greater number of participants would be needed to prove or disprove our hypothesis. As our hypothesis states that lowering breathing rate reduces the psychophysiological symptoms of stress, it would be useful to show statistically significant reduction of EDA levels. This reduction would be an indication of stress reduction occurring as a result of lowering the breathing rate due to the synchronization of the body with the haptic action of the sleeve.

The results from the self-reported data show a positive correlation between the slow pace of haptic action and a perception of calmness and a negative correlation between the fast pace of haptic action and a perception of calmness. The experience of participants in the Slow group, whose sleeve produced haptic action at a pace equal to their relaxed breathing rate, was reported as being more positive and comforting than the experience of participants in the Fast group, whose sleeve produced haptic action at a pace higher than their relaxed breathing rates. The experience of wearing a sleeve producing fast haptic action was reported as being more discomforting than wearing a sleeve with no haptic action.

The results from the self-reported data suggest a slow pace of haptic action may help promote calmness.

Because the haptic action defined in this study includes the stimulus of warmth, pressure, and feeling of movement along the arm, the individual contribution of each stimulus separately in the perception of calmness is unclear. The shape memory alloys that were used to make the actuated sleeve produced warmth and pressure simultaneously. To better test the impact of the felt sensations separately, a different sleeve design would be required. To address this issue, the second study I conducted [chapter 3] includes the design of a programmable affective sleeve made from inflatable materials and embedded heat pads. Another problem with the shape memory alloys is that precisely because the warmth and pressure are caused simultaneously, the sensations are difficult to control independently. Moreover, due to the limitations of the material, the felt pressure was very gentle. A stronger pressure stimulus might improve the impact of haptic action on psychophysiology.

It is not clear from our study design and results whether the impact of the haptic action on the perception of calmness is due to a direct physiological response or to an increase in one's awareness of their bodily rhythms, or both. I believe that the fact that some participants did not notice some of the produced sensations, such as the rhythmic activation along the forearm, could be an indication of the sleeve's possibility to subliminally affect one's psychophysiological symptoms of stress. Although further studies are needed to evaluate the conscious or unconscious effect of the sleeve's haptic action, this study hints at a promising method for emotion regulation that is material-mediated.

3.2. [STUDY II]: AFFECTIVE SLEEVE II: STUDY ON THE AFFECTIVE ASSOCIATIONS AND PSYCHOPHYSIOLOGICAL IMPACT OF A PROGRAMMABLE PNEUMATIC SLEEVE WITH HAPTIC ACTION

3.2.1. INTRODUCTION AND SCOPE

This study has a double aim. The first aim of the study is to re-test the hypothesis that the pace of haptic action has a positive correlation to the wearer's breathing rate. The results of the first study [chapter 3.1] demonstrated that a pace of haptic action higher than one's relaxed breathing rate can increase breathing rate and reduce the perception of calmness. However, we were not able to show that a haptic action equal to the relaxed breathing rate of the wearer can reduce the wearer's breathing rate: The group wearing a sleeve with haptic action equal to their relaxed breathing rate did not have a lower increase than the control group, a fact that could be attributed to the novelty of the intervention. The second aim of the study is to inquire further into material-affective associations, including the testing of more conditions of haptic action, that could potentially lead to a affective repertoire of material sensations.

In the second study, I decided that several experimental and methodological parameters would have to be redesigned. First, I decided to include a third experimental group, where participants would wear a sleeve with haptic action slower than their relaxed breathing rate (BR). In the first study I included a group of participants wearing a sleeve with a pace equal to their relaxed BR (Slow group) and a group of participants wearing a sleeve with pace higher to their relaxed BR (Fast group). It was assumed that as a result of their stress response, participants would exhibit a higher than relaxed BR during the stress-inducing task, and that haptic action equal to their relaxed BR would cause their BR to decrease and promote relaxation. In the second study, I decided to not include a stress-inducing task, but test the impact of three sleeve paces in a more neutral experimental setup.

The stress inducing task introduced a greater degree of complexity in the study as the design of the test itself can have an impact on the results. Analyzing the results of the qualitative survey in the first study, we arrived at an interesting question regarding the affective impact of the sleeve: did the sleeve have a psychophysiological impact because of the conscious awareness of its haptic action, or did the sleeve have a subliminal impact on participants' psychophysiology? When some of the participants noted that they were not aware of the sequential nature of the haptic action (the fact that the cuffs were activated one by one in sequence), we wondered whether participants had been too focused on the quiz to notice. Thus

I thought that a second study without a stress-inducing (and attention-requiring) task would be useful in order to test the dimension of conscious or subliminal affective impact of the sleeve.

Moreover, I decided that watching a nature documentary as part of the baselined phase, as happened in study I, was perhaps not ideal for promoting relaxation as individual responses to the contents of the video may vary. I decided that a more neutral task should be required for the baseline. Third, in the second study my aim was to test the sensations of pressure and warmth separately and together. In the first study the sensations were bundled together because of the behavior of the nitinol wires which change shape when heated. While this was considered a benefit while designing the first affective sleeve -- and I still consider this a benefit when the sleeve is thought of in terms of its sustainability dimensions -- it limited our ability to study the two haptic stimuli separately. Based on responses in the qualitative surveys of the first study, we hypothesized that the pace of haptic action, which may have an impact on the perception of those stimuli, was worth exploring further.

Beyond the problem of bundling the sensations of warmth and pressure together, the design of the first affective sleeve was problematic for a few more reasons. A structure using nitinol wire and fabrics was not easy to control: the behavior of the sleeve might have changed slightly over time, becoming less responsive after repeated heating. Also, the actuation of the nitinol-based cuffs was slow, limiting the range of programmable behavior; and the sensation of pressure was rather light. Conclusions about the psychophysiological impact of the haptic action of the sleeve were sometimes hard to tease out for this reason -- was the result subliminal or the sensations too light to be perceived?

The second study explores the affective impact of various conditions of haptic action. In this first study, we programmed the sleeve to produce a sequential activation of the cuffs, moving from the wrist towards the elbow. This was to some extent an intuitive decision, as we programmed the actuation sequence based on the body scanning meditation process. After the study, however, I was curious to know whether different kinds of patterns of haptic action, such as a simultaneous activation of all the cuffs, would produce similar or different results, and if similar, if they would intensify or lessen the sleeve's psychophysiological impact. My hope was that by testing various conditions of haptic action, including rhythms of synchronization such as a full or half breathing cycle, along with variations in warmth and pressure, I would be able to develop an affective material repertoire that could be used for the purpose of material-mediated interpersonal emotion communication explored in the third study [chapter 3.3]. To my knowledge, no previous studies have been conducted investigating the affective response to a variety of haptic stimuli along the forearm or the impact of those stimuli on the wearer's physiology.

In order to begin developing such an affective material repertoire, much of my research was dedicated to affective evaluation methods that would allow me to map the different physical sensations to different affective states. I decided that it was important to design and develop a custom User Interface (UI) where the participants in the study would be able to evaluate the haptic sensations. In order to obtain better insights into the results, I decided to develop a UI survey with more refined tools. This decision affected the course of my research, leading to the third study [chapter 3.3] that is almost exclusively based on the development of a User Interface for material-mediated affective communication.

3.2.2. METHODS

3.2.2a. THE DESIGN OF THE AFFECTIVE SLEEVE II

For the second version of the affective sleeve, I decided to use inflatable fabrics because of the good actuation control they provide, their light weight, low cost, and seamless integration into wearables. In recent decades, a variety of pneumatic materials have been developed for applications in robotics and biomedical applications [Althoefer, 2018; Cianchetti et al., 2918]. In deciding on the use of inflatable materials, I assumed that the pressurization of the inflatable parts would cause a sensation of pressure, but how this pressure would be controlled, how the heat component would be incorporated into the system and controlled, and what the sleeve would look like remained to be resolved.

My first approach was to design the sleeve as a garment made of soft fabric and incorporate inflatable material inserts. I developed a series of sleeves that were made of flannel, fleece, and felt fabrics. The first iteration of this sleeve was made using two layers of fleece fabric sewn together in five places, creating five compartments or horizontal zones that acted as pockets for the inflatable inserts [FIG II. 1]. The inflatable inserts were made of heat sealable nylon fabric sealed along all four edges. To account for the shape of the forearm, which widens towards the elbow, I designed the sleeve in a simple trapezoid shape. The five inflatable inserts varied in size, following the overall shape. Regarding the heating element, the idea was that narrow-sized thin, flexible heat pads would also be inserted in each of the five individual pockets.

When testing this first design, a significant problem was that the felt pressure was very light. I attributed this problem to the fact that the inflatable inserts were too narrow, containing only a small volume of air. I thought that if I could fit larger inflatable pockets into the sleeve, more pressure would be generated. I came up with a design of a two-layer fabric sleeve in which the upper layer is pleated, allowing for expansion when inflated [FIG II. 2]. The third iteration was made to be reversible so that the inflatable inserts could be hidden in the interior part of the sleeve [FIG II. 3]. The sleeve was made from a double layer of flannel cotton fabric whose the folds were created and from fleece material for the part of the sleeve that was in contact with the skin. Although the structure of the sleeve was aesthetically pleasing, it felt very warm and the complexity of the wrapping design presented technical challenges.

Although in the last two design iterations the inflatable inserts were much bigger in size the feeling of pressure was still not as strong as I

FIG II. 1
Early prototype of the pnematic Affective Sleeve consisting of two layers of fleece fabric sewn together in six places, creating five compartments that act as pockets for the inflatable inserts. Top view of unfastened sleeve (top). Side view of the fastened sleeve (bottom)

FIG II. 2
Early prototype of the pnematic Affective Sleeve made from two-layers of wool felt fabric. The upper layer is pleated, allowing for expansion when inflated. Top view of unfastened sleeve (left). Side view of the fastened sleeve (next page, top)

FIG II. 3
Early prototype of the pnematic Affective Sleeve made from flannel cotton fabric. The sleeve was made to be reversible so the inflatable inserts could be hidden in the interior part of the sleeve. Various views depicting the pockets and the reversibility of the sleeve.

desired. To overcome this problem, I gave the inflatable inserts a pleated shape, allowing for greater air volume [FIG II. 4]. The pressure was more noticeable with the pleated inserts but there were still a couple of problems. When pressurized, the inserts would make distracting sounds as the material folded around the forearm. The experience of wearing the sleeve was not pleasing, and the feeling of pressure varied slightly in each repetition due to micromovements inside the sleeve.

Through the various design iterations I became aware that the main problem was the fact that when the fabric inserts were inflated, the sleeve tended to transform into a straight columnar shape, moving away from the arm instead of wrapping around the arm and pressing against the skin. This natural material behavior upon inflation, limited the capacity of the sleeve to provide haptic action. Moreover, the shape and volume of the sleeve can be distracting to the wearer, as it tended to balloon upon inflation. I soon realized that although I was aiming for a “smart” programmable sleeve, my sleeve was lacking intelligence and a new design approach had to be adopted. I decided to lower the complexity of the design by utilizing the inflatable fabrics as inflatable cuffs rather than inflatable inserts.

In the literature on materials, design, and engineering there are already examples that utilize inflatable materials to achieve programmable actuation – i.e., to force the material to curve in the desired manner upon inflation [Yao et al., 2013; Sparrmann et al., 2021; Cappello et al, 2018]. However, none of the existing examples offered a good solution for wearable materials. For example, Cappello et al. [2018] describe methods for creating soft actuators consisting of a top and bottom layer of fabric and a bladder in the middle. Because the two layers of fabric have different properties, one side of the actuator elongates more than the other. The proposed methods are not suitable for a sleeve because the complex multilayer design does not permit enough curvature and actuation strength.

In another design, Capello et al. use two inserted bladders and three fabric layers. The use of a pleated fabric in one of the fabric layers increases the anisotropy of the material. Although this method produces greater curvature, it would not be suitable for wearables because of the shape of the material transformation. The material transforms from a flat shape to a curved, voluminous shape with bumps (created by the air that is now filled in the pleated pockets). However, because the bumps are on the outer side of the sleeve, if a sleeve was made from this method, the bumps would press not against the skin but towards the environment, thus not producing enough felt pressure [Capello et al., 2018].

Designs similar to the one proposed by Cappello et al., have also been

FIG II. 4
Iteration of the pneumatic inserts. The inserts have pleated shape to allow for greater volume when inflated.

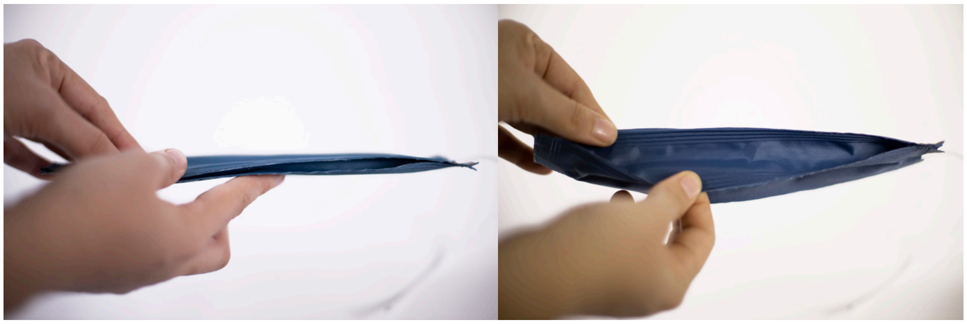


FIG II. 5
Prototype of the pre-final Affective Sleeve. A cuff made of a two level folded fabric strategically sealed in order to change shape upon inflation producing enhanced pressure sensation when wrapped around the arm. View of the cuff when not inflated (top). View of the cuff when inflated (bottom)

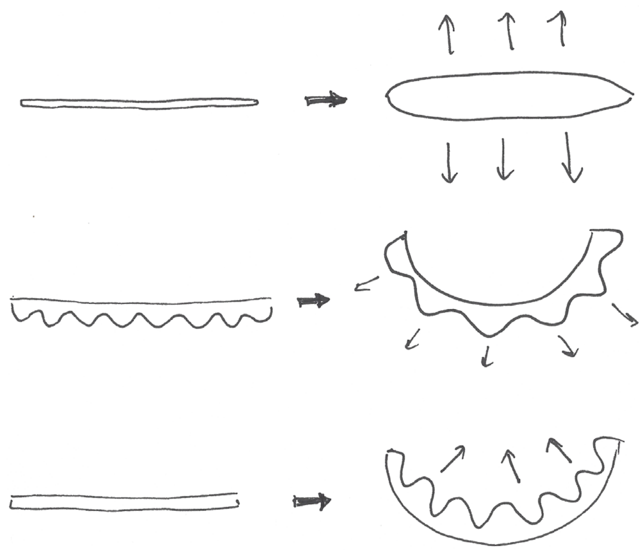


FIG II. 6
Sketch showing the natural behavior of a fabric bladder upon pressurization (top), the behavior of a programmable pneumatic fabric actuator based on the common approach in prior inventions and science literature (middle), and the behavior of the programmable pnematic fabric actuator I developed (bottom).

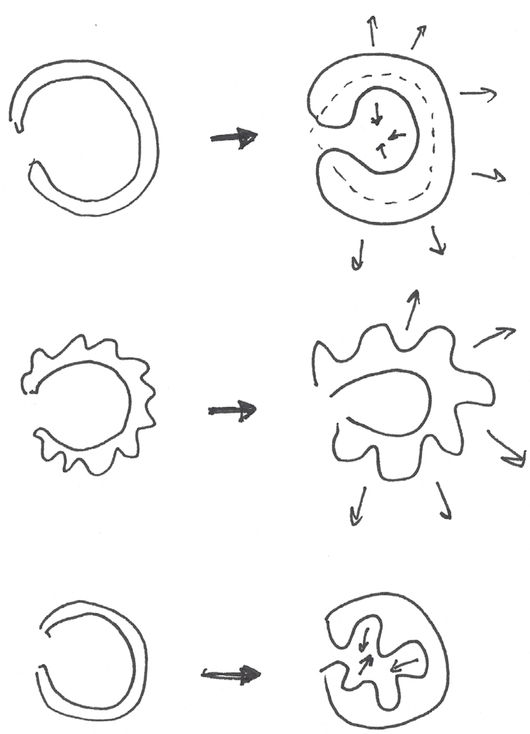


FIG II. 7
Sketch showing the natural behavior of a fabric bladder upon pressurization if forced into the shape of a sleeve cuff (top), the behavior of a programmable pneumatic fabric actuator based on common approaches in prior inventions and science literature, if it were used as a sleeve cuff (middle), and the behavior of the programmable pnematic actuator I developed when

used as a sleeve cuff (bottom). In the latter case, all the amount of pressure is directed towards the skin.

proposed been by others. For example, Galloway et al. [2017] developed soft actuators composed of fabrics and an in-between bladder. Again the complexity of inserting a bladder would be problematic, and the material bumps would again form on the outer layer when the actuator was pressurized. The design presented an additional problem due to the material being extensible, so that the shape would change through material stretching. In wearables, having a material with high elasticity reduces the feeling of pressure as it molds around the arm. This is the reason why materials other than fabric -- for example rubber or latex -- would be ineffective.

An approach utilizing fabric without the need of an inserted bladder, is followed by Ou et al. [2016] who propose a method for the pneumatic transformation of inextensible fabrics utilizing heat sealing. The material compositions have an upper and bottom layer of coated fabric (or other inextensible material, like paper) and the transformation depends on what the researchers refer to as a “hinge mechanism” -- the heat-seal between the two layers. This seal can be in the form of a line, an arc, or a diamond, and constrains the material curvature upon pressurization. The hinge angle defines the bending angle, and the side of the material in which the heat-sealing is performed defines the orientation of bending. This method is successful in that it utilizes the heat-sealing to constrain the material but, when considering wearables, it does not resolve the felt pressure issue.

To proceed to a design that would provide the required control and felt pressure, it became obvious that a solution needed to be found that would involve a novel type of pneumatic actuator, one that would fold around the arm upon pressurization, increasing the felt pressure [FIG II. 5-7]. Prior inventions and academic research in pneumatics, although varied, seemed to rely on one common principle: the difference between the upper and lower material layers in their ability to extend. In some cases this was achieved through varied elasticity properties and in other cases by constraining the material locally. I thus decided to utilize this principle to embark on a design exploration in order to create a pneumatic actuator, which, when used as the cuff module of a pneumatic sleeve, could provide the desired programmability and feeling.

After various material experiments, I decided to use the pleated inflatable fabric structure I had created earlier in order to achieve more volume upon pressurization and constrain it in various places to test its behavior. The first successful material test arrived when, in the two-level (four layer) inflatable fabric structure, I tried an alternate pattern of constraining zones utilizing heat sealing. The two-level pleated fabric structure when sealed all around its edges and in addition locally heat-sealed in alternate manner at the bottom and top layer curves inwards and towards the level with the smaller constrained area. The result was exciting, as fabric curved in the desired direction; if produced as a cuff, it would tend to push towards the skin when pressurized [FIG II. 5, 8].

I realized that by controlling the constrained area in two levels of the fabric structure, I could program the structure to curve inwards or outwards and the greater the difference between the constrained areas the greater would be the curvature. I had thus created a method to program pneumatic structures and arrived at the optimum configuration for the wearable sleeve by constraining the upper level of the structure along all its edges and the bottom levels only in certain intervals, to allow for the material to take a smooth curve when folded. What was also convenient about this method was that the structure could be created from a single material sheet folded in a certain manner and constrained in certain places. This method would be cost effective, when one considers the production and scalability of the structure, and easy to produce.

An advantage of this new pneumatic structure is that because the edges of the two fabric levels are sealed, four wings are created that allow one pneumatic structures to be inserted into another. This design allows individual structures to be connected using conventional mechanisms such as buttons or thread, as there is no risk of puncturing the structure. When a series of these individual structures is used to compose a programmable pneumatic sleeve, one structure's wings overlaps the next structure's wings, offering maximum coverage of the forearm. To create a sleeve that follows the natural shape of the arm, two-level fabric structures of gradually increasing length can be created, each fitted under the preceding structure's wings.

The final prototype was made in the previously described manner, with the addition of heating pads [FIG II. 8-11]. The material used was nylon ripstop fabric coated on one side with thermoplastic polyurethane (TPU). Another advantage of this folding fabrication method is that only one side of the initial piece of fabric needs to be coated. The addition of the heat pads created additional challenges, as the coated side of the fabric had to be protected from heat. I thus placed the heat pad on top of the coated fabric and added an additional piece of coated fabric on top of the heat pad, placing the uncoated side on the heat pad. This allowed the two levels to connect while protecting the structure from the heat. A connector with a tube to pressurize each of the structures (cuffs) of the sleeve was inserted into the upper level of the structure.

The final sleeve was made from 70 denier thick black nylon ripstop fabric. This is a very lightweight fabric, especially compared to other heat-sealable fabrics on the market that are usually at least 200 denier thick. At first, thicker fabrics were tested for the prototype (around 200 denier).

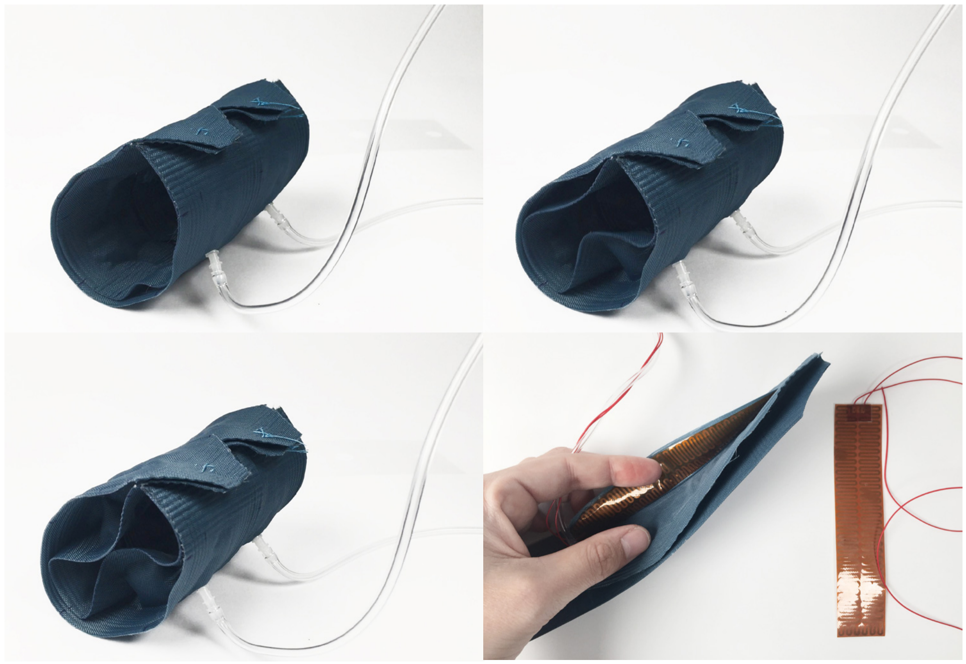


FIG II. 8
Two cuffs of the prefinal protype connected together. When the cuffs are inflated the inner layer of the cuffs is in distance from the skin. When the cuffs are inflated the inner layer of the cuffs produces felt pressure to the skin. A heatpad is integrated inside the outter layer of each cuff to produce felt warmth upon inflation.

FIG II. 9
The final protoype is designed with the same principles as the prefinal (FIG I. 8) but is made from ripstop nylon fabric and has refined details for better user experience. The sleeve is modular and is comprised of 5 cuffs allowing adjustment based on each individuals' body. Upon inflation, each cuff curves inwards wrapping around the body, producing warmth and pressure sensations in optimum manner.

FIG II. 10
Final protoype of the peunmatic Affective Sleeve. View of the unfastened prototype showing how the cuffs overlap with one another allowing both individual control and maximum coverage.

FIG II. 11
Final protoype of the pneumatic Affective Sleeve. Side view of the fastened prototype. The outer view of the prototype remains the same in both inflated and not inflated states.

Thicker fabric tests gave good results in terms of shape transformation but when applied around the arm did not feel comfortable. Moreover, while inflating, the material would wrinkle and un-wrinkle in a manner that produced a slight but distracting sound. That was not ideal for the experimental conditions I was aiming for where no sound sources would be present in the room except for the ambient environmental sounds .

The problem with fabrics thinner than 200 denier, especially those of less than 100, was that the material was often not strong enough to support the force of the pneumatic actuation and would rip at the seams. The 70 denier nylon ripstop fabric was unique in its behavior, as it was strong enough to support the actuation but soft and light enough to provide the desired user experience. The sleeve was made of five cuffs, each made from the ripstop fabric in the method described earlier to create a two-level, four layered structure with an integrated heat pad. The width of each cuff was decided to be five centimeters. As the cuffs overlapped, the overall length of the sleeve was twenty centimeters. I based the length of the sleeve on a fit-for-all measurement and the width and number of cuffs on the optimum produced haptic action (a thinner cuff would be weaker and feel more localized) [FIG II. 9-11].

I created a modular system of ten cuffs ranging from 22 to 36 cm, each cuff being greater in length than the other by specific increments. From those ten cuffs only five were chosen for the participants' sleeve, starting from the cuff with suitable length for the participant's wrist size. Each cuff was autonomous in its behavior to support the modularity of the design and allow for optimum programmability and full capability for actuation. One challenging detail was choosing the type of connection mechanism to use for fastening the cuffs around the forearm. When snap fasteners were used, the pressure from the inflation would unfasten the sleeve; if regular sew-on buttons were used, the pressure from the inflation would loosen the thread. The solution was found when I tried hook fasteners, as these are made specifically for resisting tension forces. For the connection of the cuffs snap fasteners were used, placed in the heat-sealed zones of the cuffs to avoid puncturing the sleeve [FIG II. 9-11].

3.2.2b ELECTRONICS DESIGN

Given that I wanted the pressure sensation to be controlled independently from the heat sensation, and each heat-pad to also be controlled independently, a series of switches was needed for each cuff. The first configuration I designed had a controller connected to the power, a series of five relay switches connected to the controller, power, and each of the heat pads individually; two relay switches connected to the controller, power, and two motor pumps (one for pressure and one for vacuum); five tubes, each connecting the pressure pump to a solenoid valve; five tubes, each connecting the vacuum pump to a solenoid valve; and a tube connecting each of the cuffs to one of the solenoids connected to the pressure pumps [FIG II.12].

The benefit of the first configuration is that it uses only two pumps, but they must be powerful enough to activate more than one cuff at a time. A mini motor pump requiring only six volts for its operation would not be able to activate the full range of pumps. If bigger, more powerful pumps were used, the motor noise would be distracting to the participants. Moreover, the pressure would not be equal in the case of the activation of a single cuff and in the case of the activation of multiple cuffs as the amount of pressure would have to be distributed based on the number of activated cuffs. Unequal pressure would result in an unequal force of haptic action, affecting the experimental results. I thus tested a second configuration.

The second electronics system consisted of the same configuration for the heat pad connection but for the pneumatic actuation it used a series of 10 relays connected to the controller and power, each of which was connected to a pair of pressure mini motor pumps and a vacuum mini motor pump [FIG. 13]. The benefit of this approach is that each cuff has a dedicated pair of pumps, ensuring that each cuff will receive the same amount of pressure regardless of the haptic action pattern (for example, when all cuffs are activated simultaneously or when cuffs are activated one at a time). The problem with this approach was that the pumps had to work continuously to inflate and deflate the cuffs. This necessity made this system very energy-consuming, especially in contrast to a system using solenoid valves: when solenoid valves are used, the air can be retained inside the cuff as long as the valve is closed.

To solve the energy efficiency issue, in the third system I reintroduced the solenoid as part of a different configuration. The heating activation system remained the same, but the pneumatic actuation required a series of 10 relay switches -- five connecting to five pressure pumps, one for each cuff, and five connecting to five solenoid valves, each corresponding to

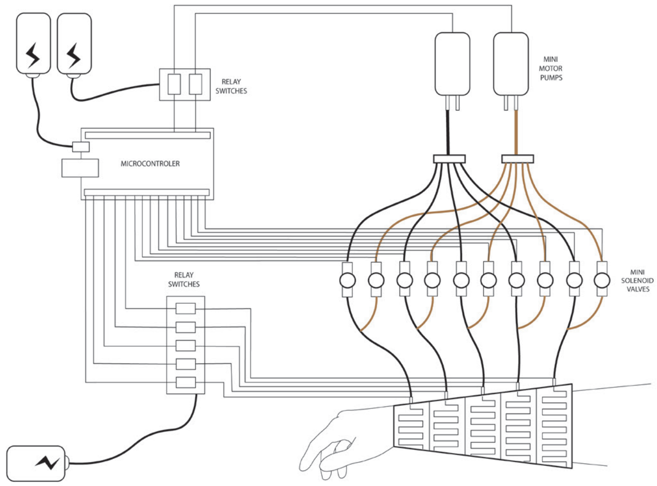


FIG II. 12
Early configuration of the electronics system. Two switches each connected to a motor pump and a vacuum pump each connected to five solenoid valves controlling the air flow ot each cuff.

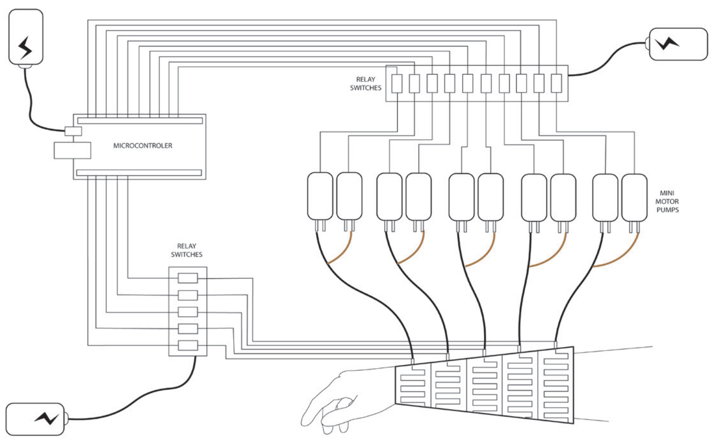


FIG II. 13
Early configuration of the electronics system. A series of switches each connecting to a pair of a mini pressure pump and a mini vaccuum pump each connected to each cuff.

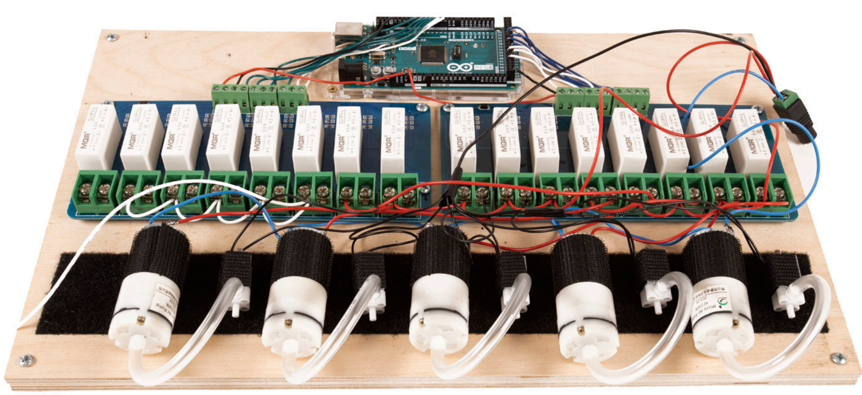


FIG II. 14
Final configuration of electronics system. A series of switches each connecting to each cuff's heatpad, a mini motor pump and a solenoid valve.

one individual cuff. There are no vacuum pumps in this configuration. The pumps do not directly connect to the cuffs, but connect to the solenoid valves and the valves connect to the cuffs. These solenoid valves are two-position three-way valves. The valve has an input connection from the pump, an output connection to the cuff, and an output exit for the air. In the open-valve state, the air from the pressure pump flows into the cuffs and the air exit is obstructed; in the closed valve state the input from the pressure pump is obstructed and the air exit is open, so the cuff that was previously inflated can then deflate naturally [FIG II. 14].

3.2.2c EXPERIMENTAL METHOD AND HYPOTHESES

This study had two goals and thus two hypotheses to be tested. Building upon the results of the first study, the first goal was to further test whether the affective sleeve could act as a material-mediated emotion self-regulation system. Unlike the first study, which was designed to elevate stress levels and test the impact of the sleeve in promoting calmness in a stress-inducing context, this study operated in a "neutral context." By this I mean that the study did not aim to induce any emotions other than those elicited by the haptic action of the sleeve. Given the tendency to synchronize our bodily rhythms with the rhythms of the environment, the impact of slow breathing on psychophysiological state, and the results from the first conducted study [chapter 3.1], I formulated the hypothesis that the pace of haptic action (including rhythmic pressure and/or warmth) has a positive correlation to the participant's breathing rate and a negative correlation to their perception of calmness.

The second goal of the study was to investigate the associations between different haptic conditions and felt emotions. Based on the results of the first study, questions arose regarding the impact of each individual sensation – pressure and warmth. The first study was limited to one haptic condition, and questions arose regarding the specificity of the affective impact of the sleeve to that haptic condition. In addition, it has been my broader goal to build a repertoire of haptic sensations and patterns in order to establish a non-verbal haptic material channel for affective communication. An investigation into the affective impact of different haptic conditions will hopefully lead to the identification of specific associations between distinct elements of the haptic conditions (produced sensations, patterns and pace of haptic action) and affective states. This study thus incorporates various combinations of pressure and/or warmth and actuation cycles. The second hypothesis I formulated is that distinct haptic conditions can be associated with distinct affective states.

To test these hypotheses, I included a Slow, a Regular, and a Fast group. In the Slow group, the pace of haptic action was slower than that of the participants' relaxed breathing rate; in the Regular group, the pace of haptic action was equal to the participants' relaxed breathing rate; and in the Fast group, the pace of haptic action was faster than the participants' relaxed breathing rate. Unlike the first study, where each of the groups was tested on one haptic condition and a separate group acted as the control group, in the second study I decided to test a variety of haptic conditions in each group, and include a control condition within the tested haptic conditions. This design would offer better numbers for statistical evaluation. I decided to include a simple setup where each participant would be tested individually while wearing the sleeve, and evaluate the felt sensations in a User Interface I designed. Like the previous study, I included real-time measurements of participants' breathing rates (BR) and electrodermal activity (EDA) [FIG. II 15-16].

3.2.2d EXPERIMENTAL PROCEDURE

The controlled study was approved by the Committee on the Use of Humans as Experimental Subjects (COUHES), established to act as the Institutional Review Board (IRB) for the Massachusetts Institute of Technology (MIT). Participants were members of the MIT community recruited through email advertisements. The advertisement informed participants that they would join a “45-minute study to evaluate the effects of material haptic sensations on emotional health and wellbeing” and that they would be compensated with a $20 gift card for their participation. The participants were also informed that they would be asked to wear a “novel wearable technology that produces the sensations of warmth and slight pressure along the forearm, and biometric sensors to collect physiology signals.” Unlike the first study [chapter 3.1], in which we concealed the true aim of the study in the recruiting and testing process, I judged that there was no risk of biasing the results if participants knew the real context of the study.[1]

To collect electrodermal activity (EDA) data, I used the Mindfield E-sense Skin Response sensor.[2] The sensor is connected to two electrodes placed on participants’ index and middle fingers and on a smartphone, where data were processed and stored using the Mindfield E-sense smartphone application. As in the first study, electrodes were placed in the intermediate phalanges to allow the fingers to move for writing or typing. In this study, there was less risk of introducing artifacts to the EDA data coming from hand movement because the most important data for analysis were gathered when the participant was at rest. To collect breathing rate (BR) data I used the Mindfield E-sense Respiration sensor. This sensor uses the same smartphone application as the EDA sensor and includes two electrodes connected to a pressure sensor. The BR sensor is placed around the participant’s chest using an elastic strap, allowing the pressure sensor (as part of the respiration sensor) to collect the data as the strap pushes on the sensor’s surface through the expansion and contraction that follows the wearer’s breathing cycle.[3]

The controlled study included four phases: (1) signing of consent form

---

1 Details of the study and its goals were revealed only at the end of the study during the debriefing phase.

2 https://www.mindfield.de/en/Biofeedback/Products/Mindfield%C2%AE-eSense-Skin-Response.html

3 https://www.mindfield.de/en/Biofeedback/Produkte/Mindfield%C2%AE-eSense-Respiration-|-Biofeedback-|-Atemfeedback.html

FIG II. 15
Study setup: Each participant sat infront of a computer and followed the study instructions in the User Interface.

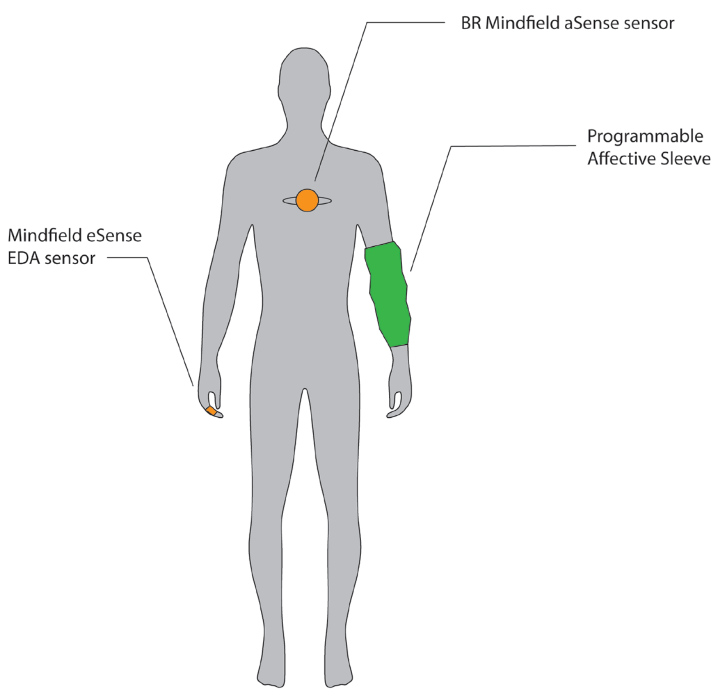


FIG II. 16
Wearable equipment in the study: Each participant wore the Affective Sleeve in the non-dominant hand, the Mindfield eSense sensor on chest to measure breathing rate, and the Mindfield eSense EDA sensor on the dominant hand to measure electrodermal activity.

(2) adjusting sensors and establishing baseline conditions, (3) testing — including habituation, testing of haptic conditions, and self-reports (4) oral interview and debriefing. The duration of the controlled study was approximately 45 minutes, including 5 minutes for reviewing the consent form, 10 minutes for establishing baseline conditions, 25 minutes for testing, and 5 minutes for the oral interviews. Participants wore the sleeve and sensors for the physiological measurements the duration of the baseline and the testing phases. The sensors were removed in the oral interview and debriefing phases. The setup remained the same throughout the study: each participant was tested individually in a multipurpose room at MIT. Participants were asked to sit at a desk, and they usually rested their arms on the desk unless typing. Participants were not prevented from moving their arms but were advised to be careful not to detach the sensors [FIG II. 15-17].

Establishing baseline conditions. After reviewing the consent form, participants proceeded to the room where the control study would take place. I helped them adjust the electrodes of the EDA on their fingers and the BR sensor around their chest. Participants were instructed to sit and relax for a few minutes. I then left the room and left participants on their own in the room for at least 7 minutes. I also instructed them to call me if needed, as I would be right outside the room. I decided to have the participants simply sit and relax as that is what they would do in the testing phase. Although sitting and doing nothing is difficult for some people, I decided to not provide a “relaxing task” (e.g. watching a nature video), as we did in the first study, so as not to introduce individual affective responses to the baseline measurement. I did not prevent them from undertaking mild activities during that time (e.g. reading), as I wanted to prevent restless behavior that might lead to a rise of EDA levels.

In the Mindfield eSense smartphone app, data were processed while captured, providing a real-time average of the calculation of breaths per minute (BPM). This was a convenient way to calculate the average BPM for each individual participant during the baseline measurements so as to program the sleeve based on each individual’s relaxed breathing rate. If this real-time average measurement was not available, I would have to disrupt the flow of the study to input the data to calculate the average. I used the BR average obtained during the baseline phase as an input to customize the sleeve’s function. At the end of the baseline phase, I interacted with each participant to adjust the sensors, retrieve the BR average, and include it in the User Interface in the testing phase. At the end of the baseline phase, before the testing began, I put the sleeve on the participant, adjusting it to their forearm size. The sleeve was worn on the non-dominant hand, to reduce movement artifacts in EDA measurements. The EDA sensor was worn on the dominant hand.

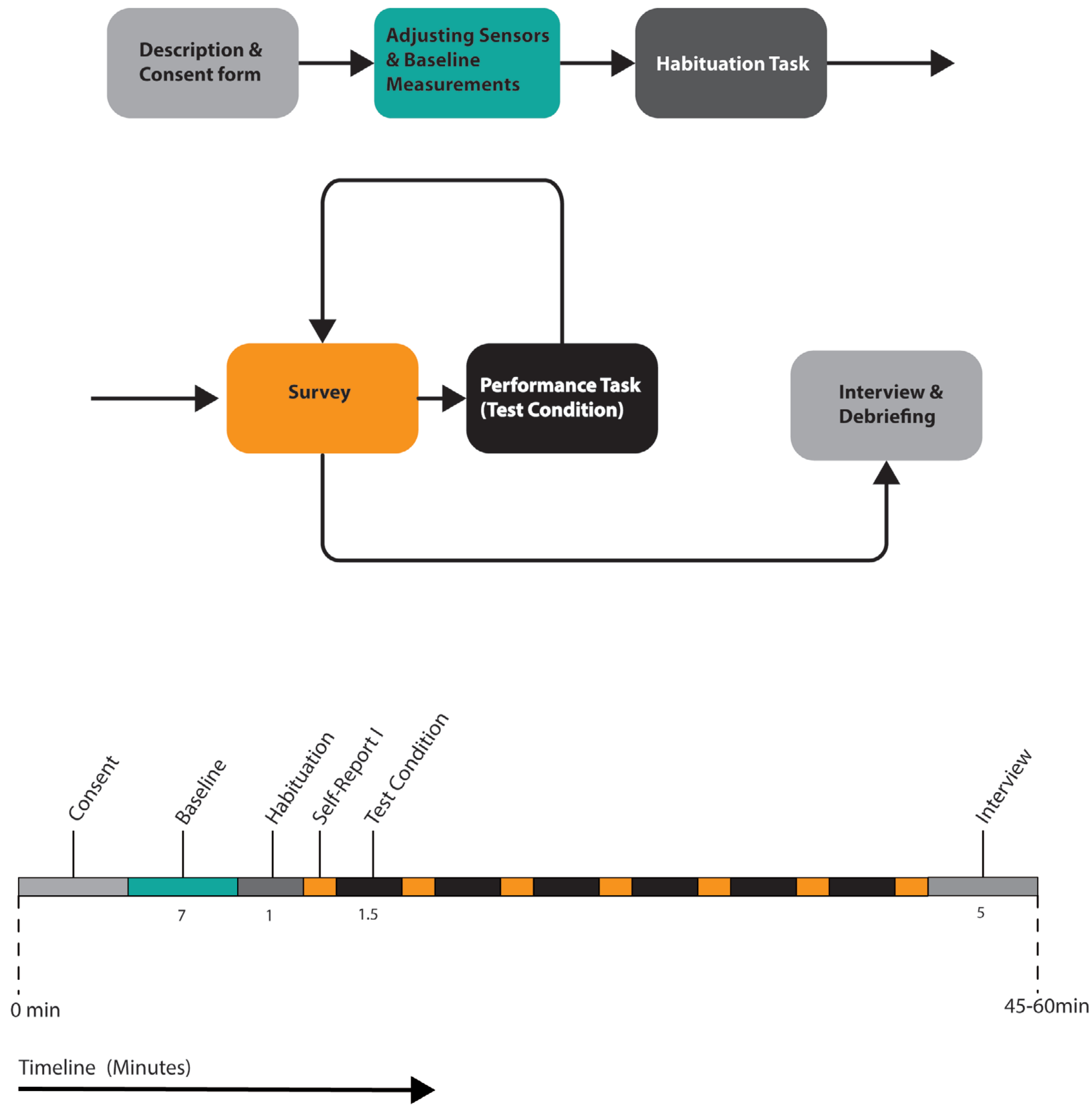


FIG II. 17
Study Procedure: The controlled study included four phases: (1) signing of consent form (2) adjusting sensors and establishing baseline conditions, (3) testing — including habituation, testing of haptic conditions, and self-reports (4) oral interview and debriefing. The duration of the controlled study was approximately 45 minutes, including 5 minutes for reviewing the consent form, 7-10 minutes for establishing baseline conditions, 25 minutes for testing, and 5 minutes for the oral interviews. Participants wore the sleeve and sensors for the physiological measurements the duration of the baseline and the testing phases. The sensors were removed in the oral interview and debriefing phases.

Testing phase. The testing phase, approximately 25 minutes, included a brief habituation phase, the testing of different haptic conditions and self-reports for evaluation through a User Interface I developed. Participants were wearing the sleeve, the BR sensor, and the EDA sensor. At first, I used two EDA sensors -- one on the participant's dominant hand, and one on the participant's non-dominant hand -- in order to compare the results from both hands. Interestingly, in the dominant hand the haptic action registered in the EDA results in a very distinct manner, with arousal peaks corresponding to the start of the pressure stimulus caused by the sleeve. I decided, however, not to use these data as I thought they were more an indication of the muscle's stimulation rather than the participant's psychological arousal. Thus EDA data from the non-dominant hand collected from the first participants were discarded from final data analysis and evaluation.

Participants were divided in three groups -- Slow, Regular, and Fast-- according to the pace of their haptic action. The pace was programmed based on each individual participant's average relaxed breathing rate, as this was determined in the baseline phase. For the participants in the Slow group, the haptic action of the sleeve was programmed to be 30% slower than their RBR. For the participants of the Regular group, the pace of haptic action of the sleeve was programmed to be equal to their relaxed breathing rate. For the participants of the Fast group, the pace of haptic action of the sleeve was programmed to be 30% faster than their RBR. The percentage of the increase and decrease of the pace of the sleeve is slightly higher than that used in the first study, which was 25%. My intention in slightly increasing that percentage was to make the difference between the groups more significant.

The exact percentage value for the pace of haptic action was determined after many self-trials in different speeds that accounted for experience and functionality factors. An adult's typical breathing rate is 12 to 20 breaths per minute. To determine the pace of haptic action, I needed to take into account upper and lower extreme values in order to reduce risk of discomfort. Thus in testings I made sure that when programmed based on a relaxed BR of 8 BPM and of 25 BPM the sleeve would operate without causing discomfort. Although the possible risks were minimal, they could interrupt the process and distort the results. Participants were informed that possible risks included discomfort due to pressure and/or warmth. In such cases the participants would inform the experimenter in order to adjust the sleeve or stop the process if the participant requested this.

Participants were randomized in each group, taking into account demographics to ensure an approximately equal number of male and female participants. Each participant was tested individually in seven haptic conditions executed in random order. The order was randomized for each participant. The duration for each of the conditions of haptic action was 1.5 minutes. After each condition, participants filled out a survey in the User Interface on which they evaluated the affective impact of the haptic condition and intensity of felt sensations. The survey had the same format for all seven haptic conditions. The testing of the seven conditions was preceded by a one-minute habituation phase where participants experienced a sample of the conditions that would be tested. The habituation phase was necessary to eliminate the novelty of the intervention. At the beginning of the testing phase, participants filled out a survey regarding their affective states in the User Interface; this served as a baseline for the evaluations received during the testing of haptic conditions [FIG II. 29].

The seven haptic conditions, adjusted to match the pace of haptic action for each group, differed in the cycle of activation: the haptic conditions were programmed based on a full cycle of breathing or a half cycle of breathing. A full cycle of breathing consists of both the duration of inhalation and exhalation; a half cycle of breathing consists of 50% of the duration of inhalation and exhalation. This means that if a full cycle of breathing of participant P has a duration of value T; in a sequential activation of the cuffs programmed based on a full cycle, the first cuff will become activated at time X; the second cuff at time X+T, the third at time X+3T, and so on. In a sequential activation of the cuffs based on a half cycle, the first cuff will become activated at time X, the second at time X+T/2, the third at time X+T, and so on.

The haptic conditions also differed in the pattern of haptic action: The conditions were programmed to produce either a simultaneous pattern of haptic action, where all cuffs produced the same sensations concurrently, making the full area of the forearm covered by the sleeve respond to the sensation, or to produce a sequential pattern of haptic action where each of the cuffs was activated one after the other. The third differentiating parameter of the haptic conditions was the produced haptic sensations: the conditions either produced only pressure or they produced pressure and warmth. The conditions were designed such that for every condition with pressure and no warmth, there was a second condition with the same parameters (cycle, direction and location) and added warmth. The seven conditions included a control condition where the sleeve remained inactive; there was no produced warmth or pressure during the control condition, although the participant was wearing the sleeve.

The seven haptic conditions are the following: Condition 1: Full activation cycle including pressure along the forearm, direction from wrist to elbow; Condition 2: Full activation cycle including warmth and pressure along the forearm, direction from wrist to elbow; Condition 3: Full activation cycle

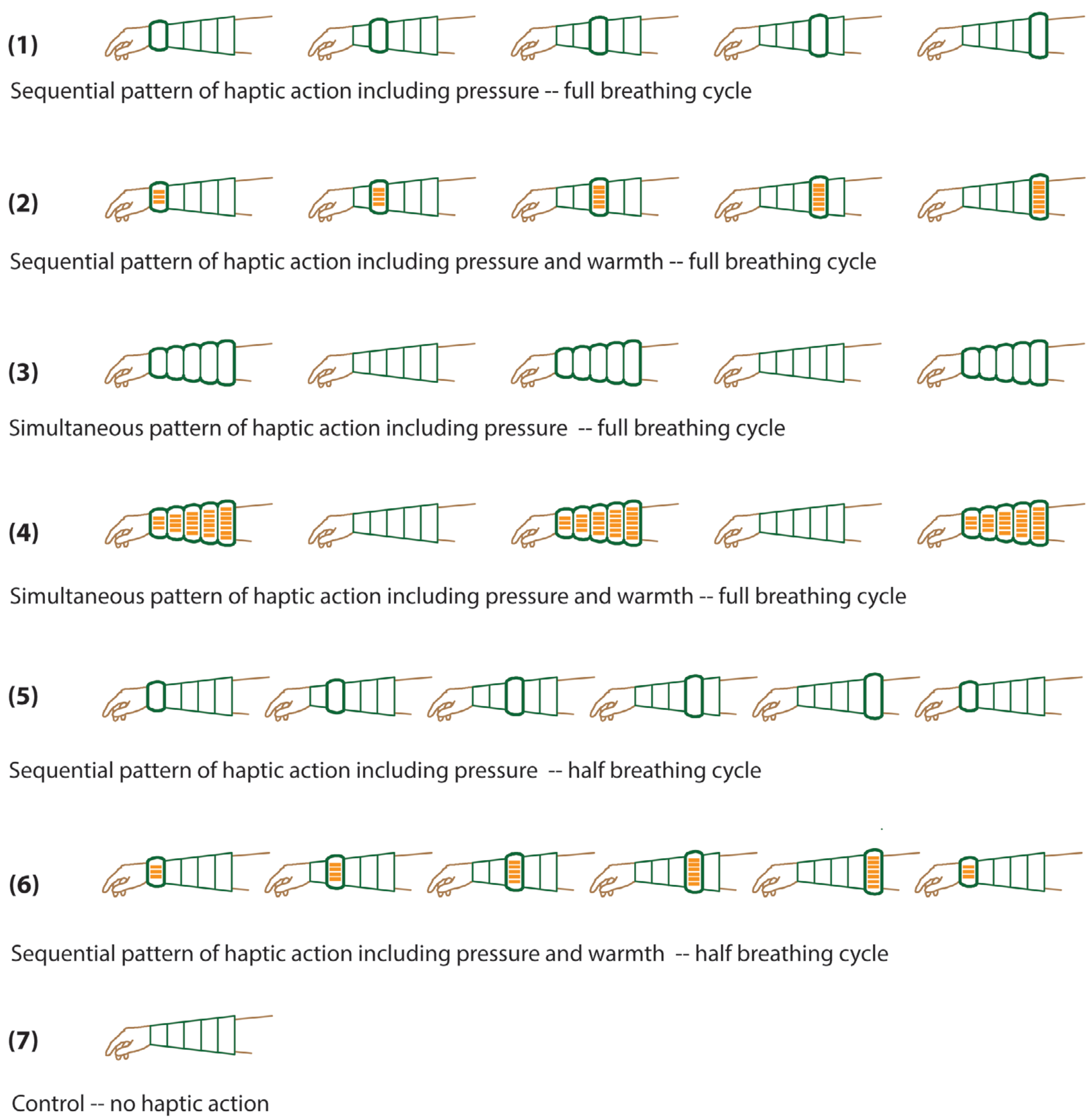


FIG II. 18
The seven haptic conditions included in the study. Condition 1: Full activation cycle including pressure along the forearm, direction from wrist to elbow; Condition 2: Full activation cycle including warmth and pressure along the forearm, direction from wrist to elbow; Condition 3: Full activation cycle including pressure concurrently in all locations of the forearm covered by the sleeve; Condition 4: Full activation cycle including pressure and warmth concurrently, in all locations of the forearm covered by the sleeve; Condition 5: Half activation cycle including pressure along the forearm, direction from wrist to elbow. Condition 6: Half activation cycle including pressure and warmth along the forearm, direction from wrist to elbow. Condition 7 (control): The sleeve is inactive, producing no warmth or pressure.

including pressure concurrently in all locations of the forearm covered by the sleeve; Condition 4: Full activation cycle including pressure and warmth concurrently, in all locations of the forearm covered by the sleeve; Condition 5: Half activation cycle including pressure along the forearm, direction from wrist to elbow. Condition 6: Half activation cycle including pressure and warmth along the forearm, direction from wrist to elbow. Condition 7 (control): The sleeve is inactive, producing no warmth or pressure [FIG II. 18]

I decided on the specific haptic conditions after several trials on a variety of parameters. At first my goal was to have haptic conditions that only produced warmth and no pressure, in addition to the ones that had only pressure and the ones that had warmth and pressure combined. Due to the design of the sleeve (with heat pad at the outer level of the cuff), if the cuff is not pressurized, the perception of warmth is very light. The design, however, offers an advantage in that the pressure helps discretize the heat sensation, which otherwise tends to feel more ambient and distributed. The heat pads take more time to cool down than warmth duration needed in each cycle of cuff activation in the haptic conditions. Thus if the heat pads are located closer to the skin, and are not discretized by the pressure sensation, the wearer will feel warmth along the forearm, pretty much in all locations covered by the cuffs, rather than under each cuff sequentially. For these reasons I decided that it was best to compare the pressure alone to the pressure with the warmth and not have a warmth-only condition.

Another parameter I initially explored through different trials was the direction of the haptic action. At first, I considered having a direction from the wrist to the elbow; a direction from the elbow to the wrist; and a direction from the wrist to the elbow and back. The reasoning behind including these additional conditions was to have more differentiation and granularity in the possible affective states elicited by the haptic conditions. After several trials, I abandoned the idea of including so many conditions, as I felt that a longer study would be tiring for the participant and the tiredness would affect the results. I also knew that if there were too many variables in the haptic conditions, it would be difficult to arrive at any conclusions through statistical analysis.

All parts of the testing phase, including the habituation, testing conditions and surveys, were integrated in the User Interface. Once the baseline phase ended, and I had adjusted the sensors and sleeve on the participant, the participant used the UI to guide them through all the steps of the testing phase, including the habituation, self-reports and the testing of haptic conditions. Instructions for the process were integrated into the UI so that no interaction with the experimenter would be necessary during the testing process except for the reporting of a problem such as discomfort or technical issue. During the testing process, I remained in the room for safety purposes but at a distance from the participant. I remained outside their visual field and did not interfere with the testing process.

Oral interview and debriefing. After the testing phase, I interacted with the participant to remove the sensors and sleeve, engage in a brief interview about their experience and then a quick debriefing, in case they wanted to know more details about the aims of the study. The interview included seven predesigned questions, though more questions could be added depending on the flow of the conversation. The predesigned questions were not always asked in the same order, as I adapted the sequence to the flow of the discussion. The questions aimed at gathering information regarding the experience of wearing the sleeve and noting any peculiarities that could not be captured in the survey included in the UI. Participants were asked to give their consent to being audio recorded during the interview process.

The first set of questions (#1 to 3) addressed the experience of the sleeve directly and aimed at capturing differences in the affective impact of the conditions. The first set of questions was: 1) How would you describe the experience of wearing a programmable sleeve with haptic action?; 2) Do you have any comments regarding the sensations (warmth and/or slight pressure) produced by the sleeve? Was there a considerable difference in felt sensations in the various conditions of haptic action you experienced? If so, could you elaborate?; 3) Do you have any comments regarding any emotions you felt due to the haptic action of the sleeve? Think of the different conditions of haptic action you experienced; was there a considerable difference in the way these made you feel? If so, could you elaborate?.

The second set of questions (# 4 to 7) addressed aspects regarding the usability and functionality of the sleeve as well as comments regarding the design of the study. The second set of questions was: 4) Do you have any comments regarding the design of the sleeve?; 5) Would you wear a programmable sleeve with haptic action if it improved your wellbeing -- for example, if it reduced your stress levels? If not, what do you think needs improvement? 6) Do you have any comments regarding the study procedure?; 7) Do you have any questions regarding the study and its goals? If so, I can provide you with more information now.

3.2.2e USER INTERFACE AND SURVEY DESIGN

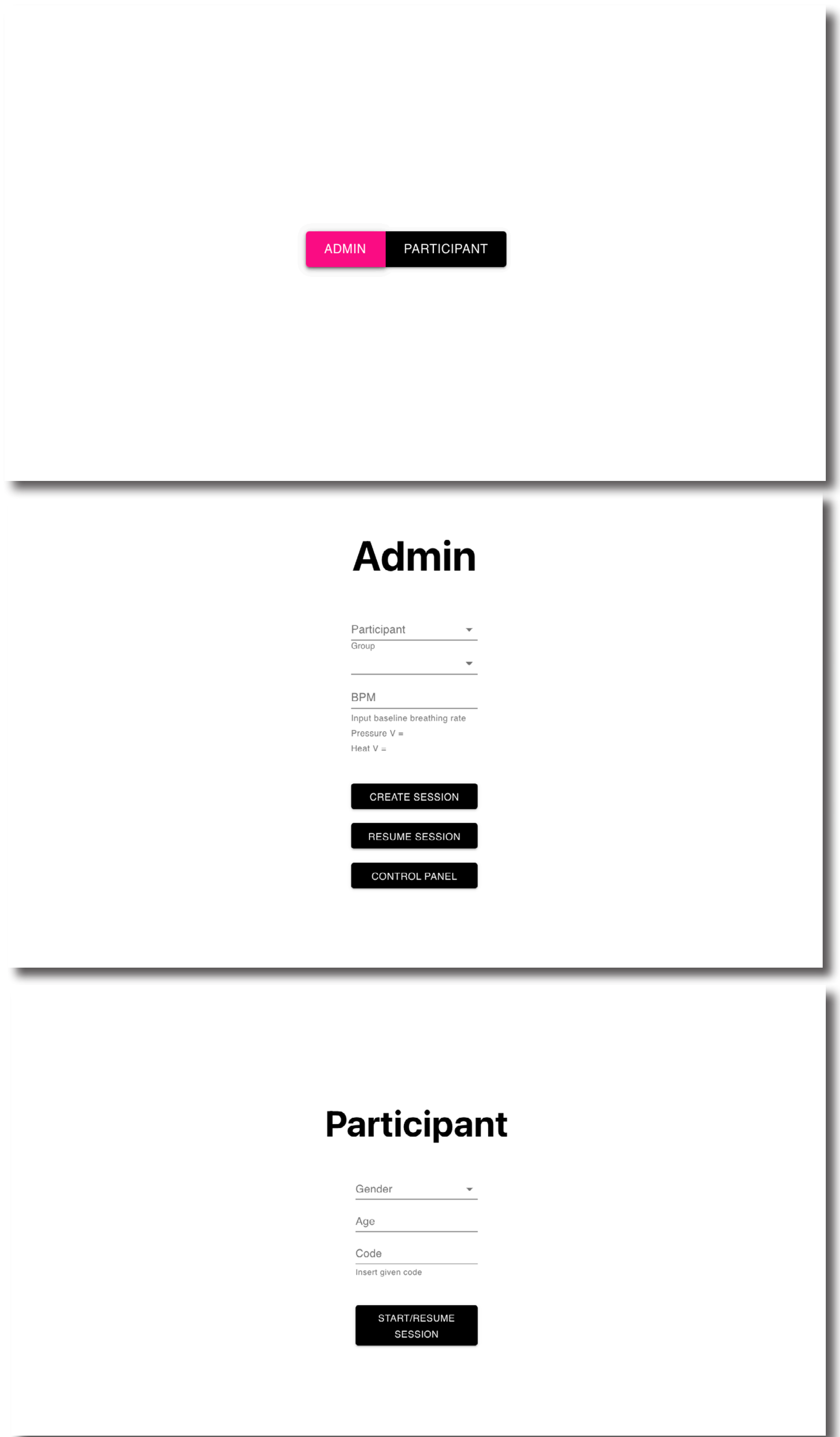
In this section I describe the user experience and interface design; in the next section I will include details that address the programmability of the sleeve, the software and network architecture of the system, and the process of gathering and storing participants information. I designed and built the User Interface from scratch using javascript in the React js framework. The UI homepage allows to a user to log in as a participant or an administrator [FIG II. 19]. The process of using the UI during the course of the control study is described below as a sequence of steps:

Admin Setup. In the course of the control study, after the baseline phase, the experimenter logs into the admin session and selects the name of the participant (pooled from a database located on a server I created), selects the group in which they wish the participant to be included (Slow, Regular, or Fast) and inputs the average BPM that is retrieved from the Mindfield E-sense Respiration smartphone application. Using the value of the BPM variable, the sleeve is instantly programmed to actuate according to the participant’s baseline and pace of the group. Based on the BPM, the voltage for the pressure and heat needs to vary in order to produce the same feeling of warmth and pressure for all participants. An integrated algorithm I defined through testing of the sleeve sensations provides the values for the voltage required for the pressure pumps and the voltage required for the heat pumps. The power of the electronic and pneumatic system is then adjusted manually by the experimenter using two potentiometers that are integrated in the system.

Participant Setup. After completing the required information (BPM and Group selection), the experimenter clicks the “create session” button which creates a unique session ID and a matching Code for the participant to input in their UI. The experimenter then instructs the participant to log in from another computer and input the unique Code in the UI. As the system operates on a network and server, both the experimenter and the participant can have access to the updated information; the participant can see what the experimenter uses as input values on the admin page. In addition to the Code, the participant self-selects gender from three options: Female, Male, and Other. The participant also inserts their age and then clicks to start the testing phase (or to resume in the event that the session had already started but was not completed because of technical or other complications).

Welcome. After the participant clicks to start the testing phase, the following instructions appear on screen: “Welcome! This study investigates the emotional impact of warmth and slight pressure sensations produced by the programmable sleeve you are wearing. The

FIG II. 19
The UI homepage allows a user to log in as a participant or an administrator.



study consists of sessions of haptic action of the sleeve (the action of the sleeve producing the haptic sensations of warmth and slight pressure) and brief surveys. Instructions on this interface will inform you about each of the steps of the study procedure. The procedure is not expected to cause any discomfort; however, if you do feel discomfort at any time, please notify the investigator. Press ‘next’ to proceed to the study.” These instructions and possible risks were also explained to the participant before signing the consent form but are repeated in the UI.

Baseline. At the next screen the instructions for the survey to be used as a baseline evaluation appear: “As a first step, you are asked to take a brief survey regarding the emotions/feelings you are having right now. The same survey, complemented with further questions, will appear in the study after the completion of each session of haptic action of the sleeve. Right now, you are asked to reflect only on your present emotions/feelings. Press ‘start’ to proceed to the survey.” As explained to participants, the same set of questions and UI appears after the testing of each individual haptic condition. The survey used as a baseline evaluation is the same, with the exception of the parts referring to the perception of warmth and pressure produced by the sleeve. The participants are wearing the sleeve at this step but the sleeve is inactive. It is activated once the habituation phase starts.

Habituation. After completing the first survey as part of the baseline affective evaluation, participants proceed to the next step: the habituation phase. A screen appears with the following instructions: “As a second step, you are asked to experience a sample of the haptic sensations of warmth and slight pressure produced by the sleeve to become familiar with the study procedure. The same haptic sensations you will be experiencing in this session, in various combinations and durations, will be produced by the sleeve during the next sessions of the study. This session will last 1 minute. Press ‘start to proceed to the session.” While the participants are experiencing a randomized sample of the haptic conditions as part of the habituation process, a screen appears with a rotating circular bar denoting that something is in progress along with the header ‘session in progress.’ Once the habituation is complete, a header “Session Completed” appears, prompting the user to click “next” in order to continue to the next phase.

Testing of haptic conditions. After completing the habituation process, participants proceed to the next phase: the testing of the seven haptic conditions (control included) in randomized order. The following instructions appear on the screen before the start of the main testing phase: “The main part of the study consists of 7 sessions of haptic action of the sleeve composed of different combinations and sequences of the haptic sensations of warmth and slight pressure. In each of the following

7 sessions, you are asked to experience the sensations produced by the sleeve. After each of the sessions, you will be asked to complete a brief survey regarding the emotions and/or feelings you experienced during the session. This procedure will be repeated until all 7 sessions have been completed. Each of the sessions will last 1.5 minutes. Press 'start' to proceed to the first session." While the testing of a haptic condition is in progress, a screen with a circular progress bar appears, similar to the one that appeared during the habituation phase, along with a header reading "session in progress." When the session is completed, the header "session completed!" appears on screen, along with a button reading "continue to survey."

Survey. Scope and Methods. The survey consists of three parts, all integrated on the same page so that participants can scroll up and down to review and complete all three parts. The first part consists of 8 questions pertaining to the subjective evaluation of the affective impact of the sleeve. The 8 questions are structured based on the Affective circumplex model as formulated by James Russell [1980]. The Affective Circumplex model represents a dimensional approach of affective evaluation where each affective state can be evaluated in two dimensions, one concerning valence and one concerning arousal. If x is the valence dimension, and y the arousal dimension of the Circumplex, all affective states can be located in the Circumplex by defining the values of their x and y coordinates. In this model, any affective state has a respective opposite state which is defined through its symmetrical coordinates to both x and y axes. The Circumplex model can be represented with certain main axes (four axes are selected here) expressing a continuum between pairs of opposite affective states [FIG II. 20 - 23].

Each of four main axes of the Affective Circumplex consists of a pair of two opposite affective states. Each of the affective states is expressed as two similar in arousal and valence feelings. The eight pairs of two opposite affective states are the following: Tense/Jittery --- Placid/Calm; Upset/ Distressed --- Serene/Contented; Sad/Gloomy --- Elated/Happy; Tired/Lethargic --- Excited/Enthusiastic. It would be consistent with the model's philosophy to present the user with a slider to choose a value between the two ends of the negative and positive spectrum. For example, the states Tense/Jittery and Placid/Calm should typically be placed at opposite ends of a slider, as the model assumes that one cannot be calm and tense at the same time. To reduce possible bias introduced by the affective model itself and keep the evaluation as nuanced as possible, I decided that each of the affective states should have its own evaluation slider. The redundancy of the system is beneficial when calculating statistics and analyzing the results.

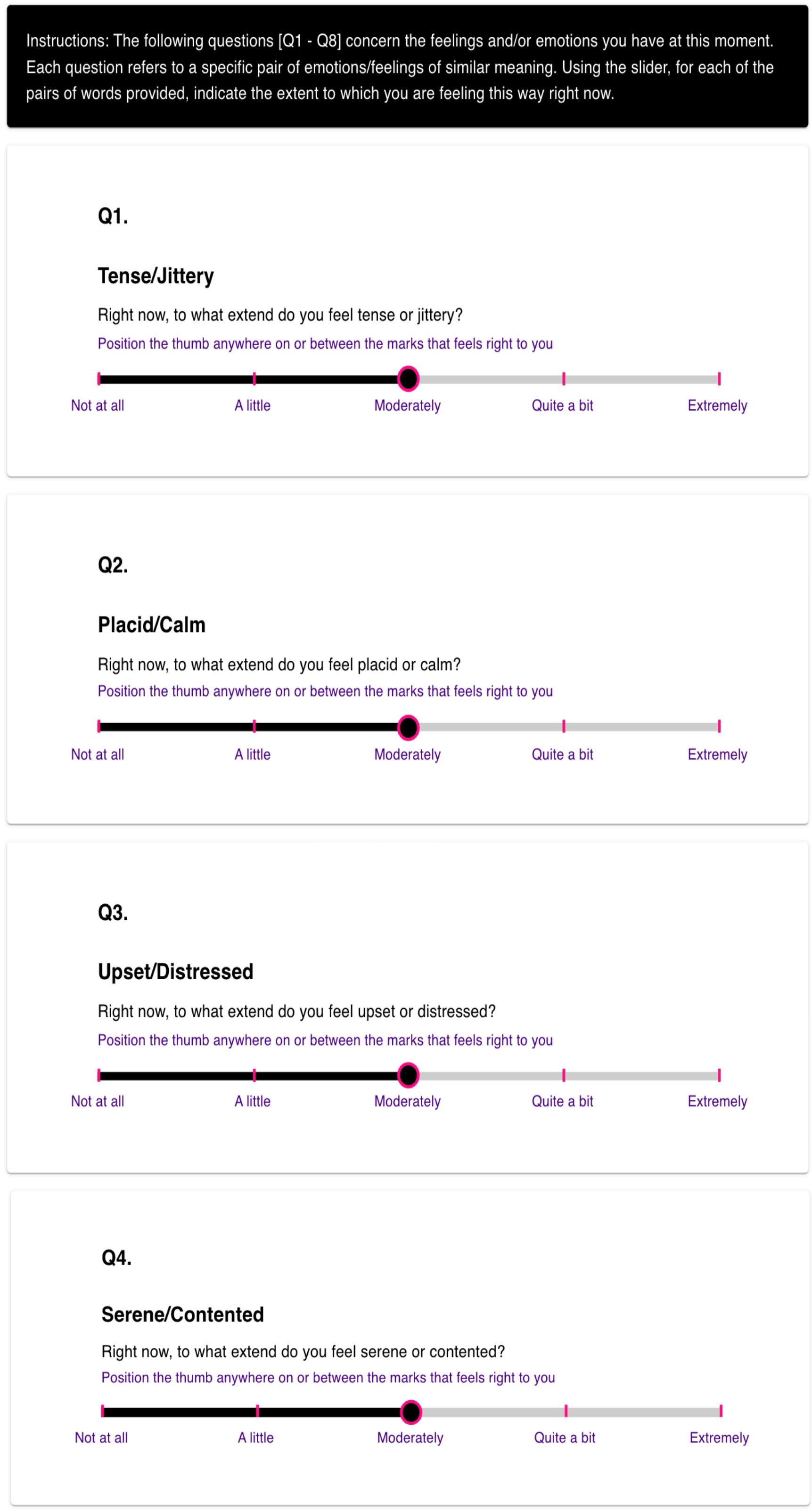
Survey. Affective evaluation. Given the previously described framework, the first part of the survey includes eight questions that prompt user input via a slider [FIG II. 20]. The section starts with the following instructions to the participant:"The following questions [Q1 - Q8] concern the feelings and/or emotions you have at this moment. Each question refers to a specific pair of emotions/feelings of similar meaning. Using the slider, for each of the pairs of words provided, indicate the extent to which you are feeling this way right now." The eight questions correspond to the eight opposite affective states and are each presented with the name of the affective state as a header -- for example "Tense/Jittery," followed by the question "Right now, to what extent do you feel tense or jittery?"

The same format is followed for all eight affective states. Each question has the following subheader prompting the user to position the slider anywhere between the two ends of the continuum. "Position the thumb anywhere on or between the marks that feels right to you." A numeric value from 0 to 100 is returned to the database once the participant submits the answers. The following evaluations are placed as markers under the slider in positions corresponding to the numeric values 0, 25, 50, 75, and 100, respectively: "Not at all," "A little," "Moderately", "Quite a bit," and "Extremely." The numeric values are not shown to the user. The user can place the slider anywhere in between markers, returning, for example, a value of 63 or 88. This design was intentional to allow for a more refined evaluation.

When the page first appears all knobs of the sliders are placed in the middle of the continuum, at value 50. It can be argued that placing the knob at a default value can bias the participants' responses, even if it is placed in the middle (denoting neutral responses or moderate reactions). I decided that placing the node in the middle would introduce less bias than placing it at either one of the two ends of the spectrum. Unfortunately, using the slider format, it is not possible to have the slider disappear so as to create no bias at all. Perhaps with a more complicated interface one can achieve that, but I also wanted to keep the design and interaction as simple and intuitive as possible. We can thus assume a small possible bias towards "neutrality" introduced through the starting slider position.

Survey. Sensory evaluation. The second part of the survey consists of questions pertaining to the perception of the sensations produced by the sleeve. The first question addresses the perception of warmth, and the second question the perception of pressure. The two questions are identical apart from the words denoting the sensations. The question pertaining to warmth is introduced with the following instructions: "The following question refers to the session of haptic action just performed -- not previous ones, if any. The question addresses the sensation of warmth you might have felt during that session -- try to focus only on the

FIG II. 20
The first part of the survey included in the UI addresses self-evaluation of the participant's affective state. It includes eight questions that prompt user input via a slider [image continues at next page].



Q5.

Sad/Gloomy

Right now, to what extend do you feel sad or gloomy?

Position the thumb anywhere on or between the marks that feels right to you

Not at all | A little | Moderately | Quite a bit | Extremely

Q6.

Elated/Happy

Right now, to what extend do you feel elated or happy?

Position the thumb anywhere on or between the marks that feels right to you

Not at all | A little | Moderately | Quite a bit | Extremely

Q7.

Tired/Lethargic

Right now, to what extend do you feel tired or lethargic?

Position the thumb anywhere on or between the marks that feels right to you

Not at all | A little | Moderately | Quite a bit | Extremely

Q8.

Excited/Enthusiastic

Right now, to what extend do you feel excited or enthusiastic?

Position the thumb anywhere on or between the marks that feels right to you

Not at all | A little | Moderately | Quite a bit | Extremely effect of warmth and not pressure if you felt both warmth and pressure. If you didn't feel a warmth sensation during that session, reply 'No' and proceed to the next question." [FIG II. 21 - 22]

The question was phrased in the above manner to test any placebo effect for the conditions that did not test for the particular stimulus. The participant was presented with a "yes/no" option to choose from. If "no" was chosen, the rest of the panel was hidden. If "yes" was chosen the participant proceeded to the next part of the question, consisting of a slider prompting the participant to rate the sensation based on "pleasantness" and allowing them to place the knob anywhere at or between the following markers: "Very Unpleasant," "A bit Unpleasant," "Neutral," "A Bit Pleasant," or "Very Pleasant." The third part of the question concerns the felt intensity of the sensations for each of the locations of the five cuffs. It consists of a drawing of the sleeve and a series of vertical slides corresponding to each of the five cuffs. The slider has five markers placed on four corresponding vertical divisions, from numeric values of 1 to 5. The slider knob is again placed in the middle, at the numeric value 3 [FIG II. 21-22].

In the third part of the question, with the vertical sliders, the participant is prompted to respond to the question using the following instructions: "If "5" is the highest and "1" is the lowest intensity of ______ (warmth/pressure accordingly) you felt during the session, what was the maximum ______ (warmth/pressure accordingly) you felt in the area covered by each of the five cuffs?" This question was challenging to form, as I had to find a minimum and maximum threshold that would be understood by all participants. I thought that setting an external reference as a minimum or maximum would not lead to accurate results; if I asked for example "Was the sensation of warmth higher or lower than a heating pad or a hot bath?" I would have to specify the kind of heating pad or how hot the bath is. Moreover, people have different notions of what a "hot" bath is and different sensitivity to temperature. I therefore decided to use the 1 to 5 range defined by each participant's subjective perception of maximum and minimum sensory intensity.

As was the case in the previous questions with sliders, the user is prompted to place the knob anywhere at or in between the numeric values used as markers. Participants are also given the option to check a box "I don't recall" underneath the respective slider. Checking the box deactivates the slider returning null as a stored value. Participants' subjective evaluation of warmth and pressure through the sliders can help the experimenter evaluate if and how the perception of the sensations changes depending on the haptic condition and/or pace of the sleeve. Also, it helps the experimenter understand which locations of the forearm are more sensitive, and if the sensitivity changes depending on the haptic conditions.

Survey. Participant's feedback. The last part of the survey prompts the participant for feedback regarding their experience with the following instructions: "The following question asks for your input regarding the experience of the haptic sensations you felt. Provide any thoughts, comments or observations regarding the experience of haptic sensations you felt during the session and possibly compare these with the experience of haptic sensations you had in previous sessions if any." The question has "Experience" as a header and includes a text box for typing the response. The purpose of this question is to collect thoughts and comments that are not directly addressed in the survey in order to help the experimenter identify affective patterns or peculiar behaviors [FIG II. 23].

FIG II. 21
The second part of the survey included in the UI addresses self-evaluation of felt sensations. Felt warmth is evaluated in terms of pleasantness and in terms of intensity per cuff.

Instructions: The following question refers to the session of haptic action just performed --not previous ones, if any. The question addresses the sensation of warmth you might have felt during that session --try to focus only on the effect of warmth and not pressure if you felt both warmth and pressure. If you didn't feel a warmth sensation during that session reply "No" to question Q9.1. and proceed to the next question.

Q9.

Warmth Sensation

Q9.1.

Did you feel a warmth sensation in the session?

○ Yes ○ No

Q.9.2.

Was the warmth sensation pleasant or unpleasant?

Position the thumb anywhere on or between the marks that feels right to you.

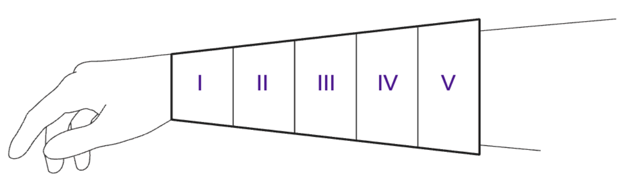
Very unpleasant | A bit unpleasent | Neutral | A bit pleasant | Very pleasant

Q.9.3.

If "5" is the highest and "1" is the lowest intensity of warmth you felt during the session, what was the maximum warmth you felt in the area covered by each of the five cuffs?

Position the thumb anywhere on or between the marks that feels right to you. Precision is not important but if you cannot recall at all please check "I can't recall". See the diagram below for cuff numbering.

Cuff I	Cuff II	Cuff III	Cuff IV	Cuff V
5 (MAX)	5 (MAX)	5 (MAX)	5 (MAX)	5 (MAX)
4	4	4	4	4
3	3	3	3	3
2	2	2	2	2
1 (MIN)	1 (MIN)	1 (MIN)	1 (MIN)	1 (MIN)
☐ I can't recall	☐ I can't recall	☐ I can't recall	☐ I can't recall	☐ I can't recall



Instructions: The following question refers to the session of haptic action just performed --not previous ones, if any. The question addresses the sensation of pressure you might have felt during that session --try to focus only on the effect of pressure and not warmth if you felt both warmth and pressure. If you didn't feel a pressure sensation during that session reply "No" to question Q10.1. and proceed to the next question.

Q10.

Pressure Sensation

Q.10.1.

Did you feel a pressure sensation?

○ Yes ○ No

Q.10.2

Was the pressure sensation pleasant or unpleasant?

Position the thumb anywhere on or between the marks that feels right to you.

Very unpleasant | A bit unpleasent | Neutral | A bit pleasant | Very pleasant

Q.10.3

If "5" is the highest and "1" is the lowest intensity of pressure you felt during the session, what was the maximum pressure you felt in the area covered by each of the five cuffs?

Position the thumb anywhere on or between the marks that feels right to you. Precision is not important but if you cannot recall at all please check "I can't recall". See the diagram below for cuff numbering.

Cuff I	Cuff II	Cuff III	Cuff IV	Cuff V
5 (MAX)	5 (MAX)	5 (MAX)	5 (MAX)	5 (MAX)
4	4	4	4	4
3	3	3	3	3
2	2	2	2	2
1 (MIN)	1 (MIN)	1 (MIN)	1 (MIN)	1 (MIN)
☐ I can't recall	☐ I can't recall	☐ I can't recall	☐ I can't recall	☐ I can't recall

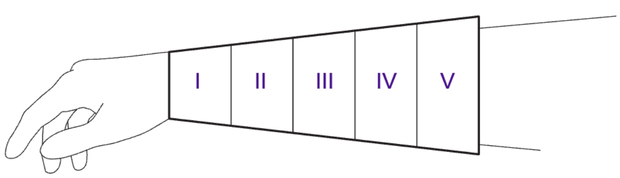
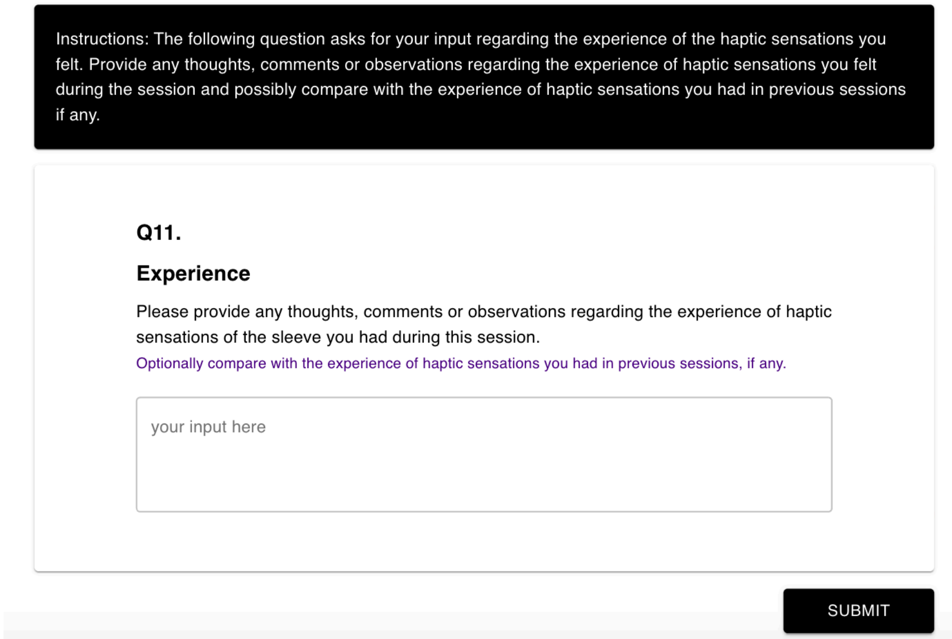


FIG II. 22
The second part of the survey included in the UI addresses self-evaluation of felt sensations. Felt pressure is evaluated in terms of pleasantness and in terms of intensity per cuff.

FIG II. 23
The last part of the survey prompts the participant for feedback regarding their experience.



3.2.2f. SYSTEM ARCHITECTURE

The coordination between the different steps and components in the controlled study presented a challenge. The testing of each of the haptic conditions needed to have a specific pre-programmed duration (1.5 minutes) but the amount of time the participant would take to fill out the survey could not be determined in advance. Some individuals would fill out the survey very quickly and some would think through each question (thus this step could take between 1 minute and 10 minutes). Setting the maximum amount of time to fill out the survey would not resolve the issue, as those waiting for the next session might start feeling restless or sleepy, influencing their affective state. To resolve this issue, the sleeve needed to be synchronized with the survey so that every time the participant would submit the evaluation survey, that participant could immediately proceed to the next session.

To allow such synchronization between the sleeve and the UI, I built a network communication system allowing different components of the system to interact in a two-way fashion. The software architecture is composed of a SQLite database, a webserver, a UI, and an Wifi microcontroller controlling the sleeve. In the database, connected to the web server built with Python Django framework, all names of participants and results from the surveys are stored. The Web server runs in the participant's laptop but also allows the experimenter's laptop to be connected to it through a wireless router, creating a local network system. The microcontroller, is also connected to the same local network. The webserver has a websocket to allow incoming and outgoing connection requests. By using a websocket when a participant finishes a survey, the UI sends a request to the server to send a request to the microcontroller to start the next haptic condition. Similarly, when a haptic condition ends, the microcontroller sends a request to the server to send a request to the UI to start the next session (pending user's request through a start button).

Every time a participant fills out a survey and hits the "submit" button, the results are stored in the SQLite database and can then be retrieved as a Json file. Another challenge, beyond that of the sleeve and the UI, is the synchronization with the data from the physiology sensors. These data are collected in the E-sense smartphone application and are not directly correlated with the sleeve or UI, as the phone is not part of the network. Technically, one can connect the sensors to the UI and server and have the data live-streamed. This however would require the appropriate licensing or software package from the sensors company and programming of all the algorithms for signal processing from scratch, whereas the benefit of using the smartphone application is that it does the low level signal processing, providing the BPM values and peak values of EDA.

As a simpler solution to resolve the matching of the physiological data to the exact times and durations of the haptic conditions, I used Unix timestamps for the start and end of each haptic condition. Every time a condition starts, a command is sent to the Web Server to store a timestamp of the condition start time, the type of haptic condition, and the timestamp of the condition end. The timestamps are then correlated with the data collected through the physiology sensors, which are stored in csv files, extracting the portions between the specific times defining the start and end of conditions. Specifically for the habituation condition, I removed the first one minute and last one minute from the recorded data and kept the in-between data (of at least five minute duration) for analysis. This is because I wanted to remove errors due to calibration and artifacts due to hand movement when sensors were adjusted by the experimenter.

3.2.3. RESULTS

3.2.3a. PARTICIPATION AND DEMOGRAPHICS

In total, 37 individuals participated in the study. All measurements of one of the participants (ID 37) were discarded from the study because the adapter connected to the pressure pumps stopped providing power during the study. Thus, in total, the results of 36 participants were used for the data analysis. Regarding gender, 21 of the participants self-identified as Female, 14 self-identified as Male, and one self-identified as Other. Out of the 36 participants, 15 participated in the Regular group, 13 participated in the Slow group, and 8 participated in the Fast group. In the Regular group, out of the 15 participants, 8 were female, 6 were male, and 1 was of other gender. In the Slow group, out of the 13 participants, 8 were female and 5 were male. In the Fast group, out of the 8 participants, 5 were female, and 3 were male.

In addition to the data of the one participant that were discarded from all results, the following data were also discarded: From a participant in the Regular group (ID 20), age 30, gender Female, BR data were discarded from haptic conditions 5 and 7 because the BR sensor became disconnected. From a participant in the Slow group (ID 34), age 25, gender Female, BR data were discarded from all haptic conditions because the BR sensor was not properly connected. From a participant in the Fast group (ID 61), age 23, gender Female, BR data were discarded due to malfunction of the BR sensor from haptic conditions 3, 4, and 6. From a participant in the Regular group (ID 25), age 36, gender Male, BR data were discarded due to malfunction of the BR sensor from the haptic conditions 2, 5, and 7. Evaluation of sensors' malfunction was done through either study observation, participants' comments, or study of the collected data.

Regarding EDA data, data were discarded for the entirety of the study from the following participants: Participant with ID 21, Group Regular, Gender Male, Age 30; Participant with ID 30, Group Fast, Age 29, Gender Female; Participant with ID 40, Group Slow, Gender Male, Age 36, Participant with ID 44, Group Female, Gender Male, Age 29; Participant with ID 66, Group Regular, Age 27, Gender Male. Data were discarded either due to poor connectivity or malfunction of the EDA sensor. In some cases the recorded signal was flat, failing to show arousal changes; in other cases the electrodes lost connection. In all cases, the electrodes of the EDA sensor were pre-gelled and taped on participants fingers. All data from the survey were successfully recorded and processed for all 36 participants.

The minimum and maximum age of all participants was 18 years and 39, respectively. The average and median age of all participants was 28.94 and 28.5, respectively. The minimum and maximum age of participants in the Regular group was 23 years and 39, respectively. The average and median age of participants in the Regular group was 31 and 30, respectively. The minimum and maximum age of participants in the Slow group was 18 years and 37, respectively. The average and median age of participants in the Slow group was 27.23 and 26, respectively. The minimum and maximum age of participants in the Fast group was 18 years and 37, respectively. The average and median age of participants in the Fast group was 27.87 and 28, respectively.

All participants were members of the MIT community. Participants were either students or staff at MIT, with the majority being graduate students. Exact numbers regarding participants' roles in the community were not recorded. The controlled study took place at MIT over the course of 5 weeks. The first participant took part in the study on February 6, 2020 and the last participant took part in the study on March 12, 2020. The study had to stop abruptly because of the Institute's measures to protect the community against the pandemic of Covid-19. Although I was initially aiming for equal participation in all three groups for a number of 60 participants in total, unforeseeable pandemic measures resulted in unequal distribution and less participation that initially planned.

Due to prolonged measures against the pandemic, including social distancing and online learning, I was not able to resume the study to complete the initial target number of participants. Although I had the option to redesign the study to be conducted online, this option presented several challenges: The setup of the study would not be the same as the first setup and thus the results of all participants that took part in the in-person study would have to be discarded. The sleeve would have to be shipped to the participants without supervision by the experimenter, thus posing minimal health risks. The sleeve would require expertise in setting up and connecting to the online survey that not all participants might have. For these reasons, the study had to be limited to the numbers acquired in the initial five weeks of in-person studies.

3.2.4.b PHYSIOLOGICAL DATA ANALYSIS

Electrodermal Activity (EDA). The EDA sensor provides two types of measurements that are useful in determining the levels of arousal: one is the general levels of the electrical conductance and the other is the number of fluctuations in the response. In principle, higher levels of conductance and higher number of fluctuations are correlated with higher arousal levels. To distinguish between the two measurements, measurements pertaining to general levels will be named EDA levels (EDA-L), and the response fluctuations will be named EDA response (EDA-R) (typical terminology is SCL and SCR, Skin Conductance Levels and Skin Conductance Response, respectively). The E-sense Midfield smartphone application conducts the first lower level filtering and also calculates EDA-R per minute. The levels of the conductance (EDA-L) are also provided in correspondence with the sensor's sampling rate, which was selected to be 5 measurements per second. EDA is measured in Microsiemens (μS).

To calculate the EDA-R per minute, the sensor uses an integrated algorithm. According to the manual of the eSense Midfield EDA sensor, there are two ways of detecting a rise in the signal: (1) the signal is constantly rising for 2 seconds; (2) the difference between the level of the signal and the base value (what counts as the start of the raise) is greater than 0.5 μS. In the second case, the app reacts to the sudden rise of the signal, counting it as a fluctuation. If the signal falls 0.1 siemens during a rise, the algorithm starts looking again for a new response. The algorithm counts the first value of the fluctuation as its base value for the fluctuation signal and during the fluctuation period detects the amplitude, which is constantly changing. The algorithm calculates EDA-R within a one-minute window and globally resulting in an EDA-R per minute value.[1]

To process the EDA values, I first calculated the average EDA-L and EDA-R values for each haptic condition and baseline session for each participant. This was possible by matching the UI timestamps with the sensor's timestamps, gathering all data in those time intervals, and calculating their average values. I then calculated the relative average EDA-L change from baseline for each condition for each participant. The relative average change was calculated with the following formula: condition EDA-L avg / baseline EDA-L avg - 1. For EDA-R values it is not possible to calculate the average relative change, as the baseline values can be zero. Thus the EDA-R absolute average change values were calculated instead with the following formula: condition EDA-R avg -

1 See eSense Mindfield sensor's maual and FAQ document, accessed 4/2021: https://www.mindfield.de/en/category/11-esense.html?download=161

baseline EDA-R avg.

As a reminder to the reader, the conditions of haptic action (haptic conditions) are the following presented in randomized order: Condition 1: Full cycle including pressure along the forearm, direction from wrist to elbow; Condition 2: Full cycle including warmth and pressure along the forearm, direction from wrist to elbow; Condition 3: Full cycle including pressure concurrently in all locations of the forearm covered by the sleeve; Condition 4: Full cycle including pressure and warmth concurrently, in all locations of the forearm covered by the sleeve; Condition 5: Half cycle including pressure along the forearm, direction from wrist to elbow. Condition 6: Half cycle including pressure and warmth along the forearm, direction from wrist to elbow. Condition 7 (control): The sleeve is inactive, producing no warmth or pressure [FIG II. 18]

When comparing the values of the average relative change of EDA levels (EDA-L) for each group for the whole testing duration (including the seven conditions combined), the levels were slightly higher in the Regular group (0.96) compared to the Fast group (0.75) and Slow group (0.74). When comparing the values of the average relative change of EDA Levels (EDA-L) for each of the haptic conditions [FIG II. 38d], the 4th condition of haptic action caused the greatest average relative change in EDA levels (0.92). This is the condition that involves simultaneous activation of all cuffs along the forearm, producing both pressure and warmth simultaneously. It is reasonable to assume that more intense stimuli (combined warmth and pressure rather than pressure alone; activating the whole sleeve at once rather than each one cuff at a time) produced higher arousal.

What is peculiar is that the third condition to cause the highest EDA-L is the control condition, condition 7 (0.85) with no warmth or pressure produced. One reason for this result is that the control condition is only 1.5-minute long and thus perhaps not long enough to change participants' physiological state given that the control condition was occurring among the other conditions. Another possible reason for this result is that participants were not notified that at some point they would experience a condition producing no sensation at all and were perhaps surprised when that happened, raising their arousal levels. Finally, another possible reason might be that the inactivity of the control condition caused restlessness demonstrated in the higher arousal levels. Some participants during condition 7 also wondered if the system broke down, as it stopped producing the expected sensation. This thought could have been anxiety provoking, affecting the results.

When plotting the EDA level values for each of the conditions for each group [FIG II. 24a - c] and each of the conditions for each of the groups

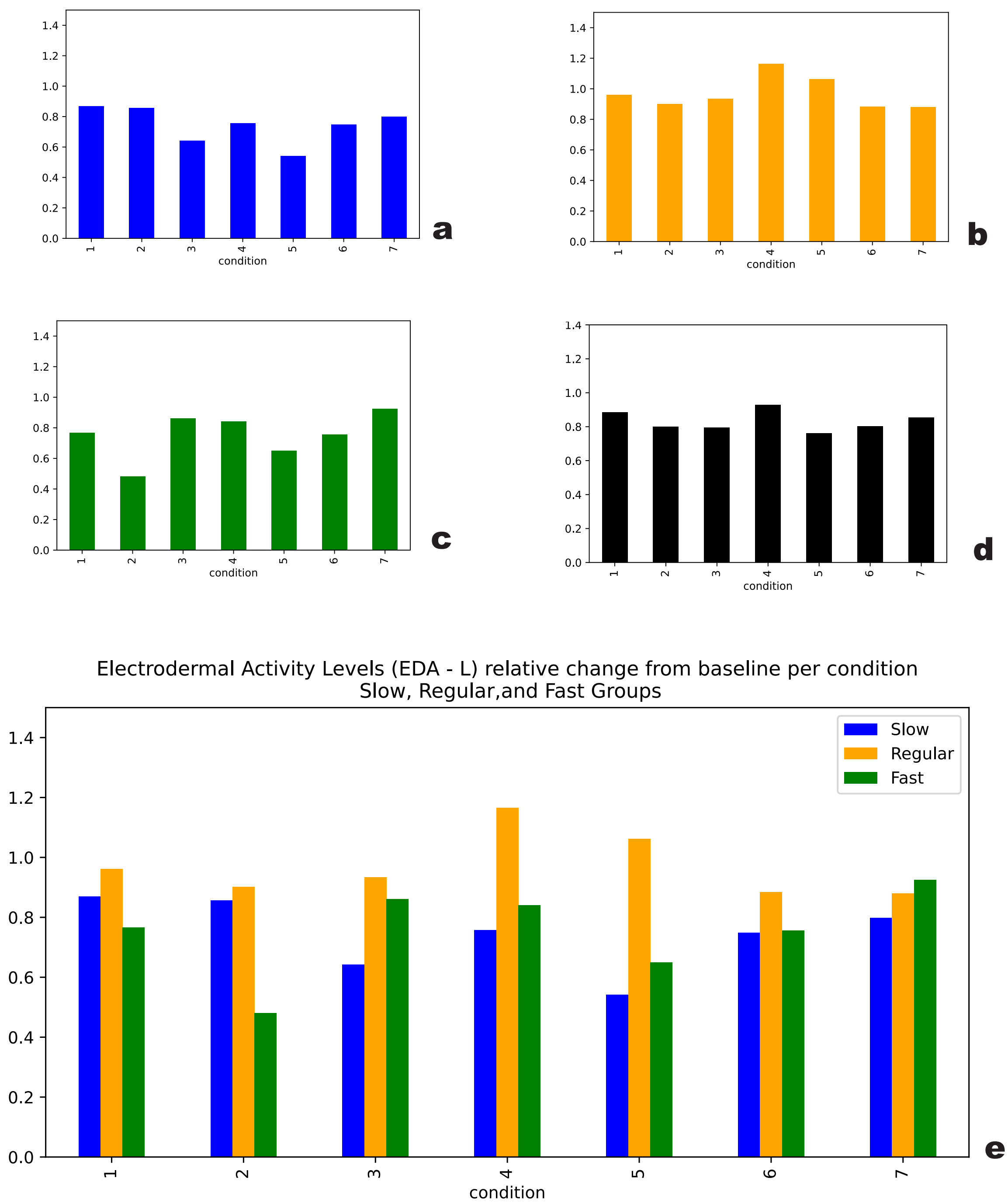


FIG II. 24
Electrodermal Activity Levels (EDA-L) relative change from baseline per condition.
a. Slow Group b. Regular group. c. Fast Group. d. All Participants. e. Comparison of Slow, Regular, and Fast groups.

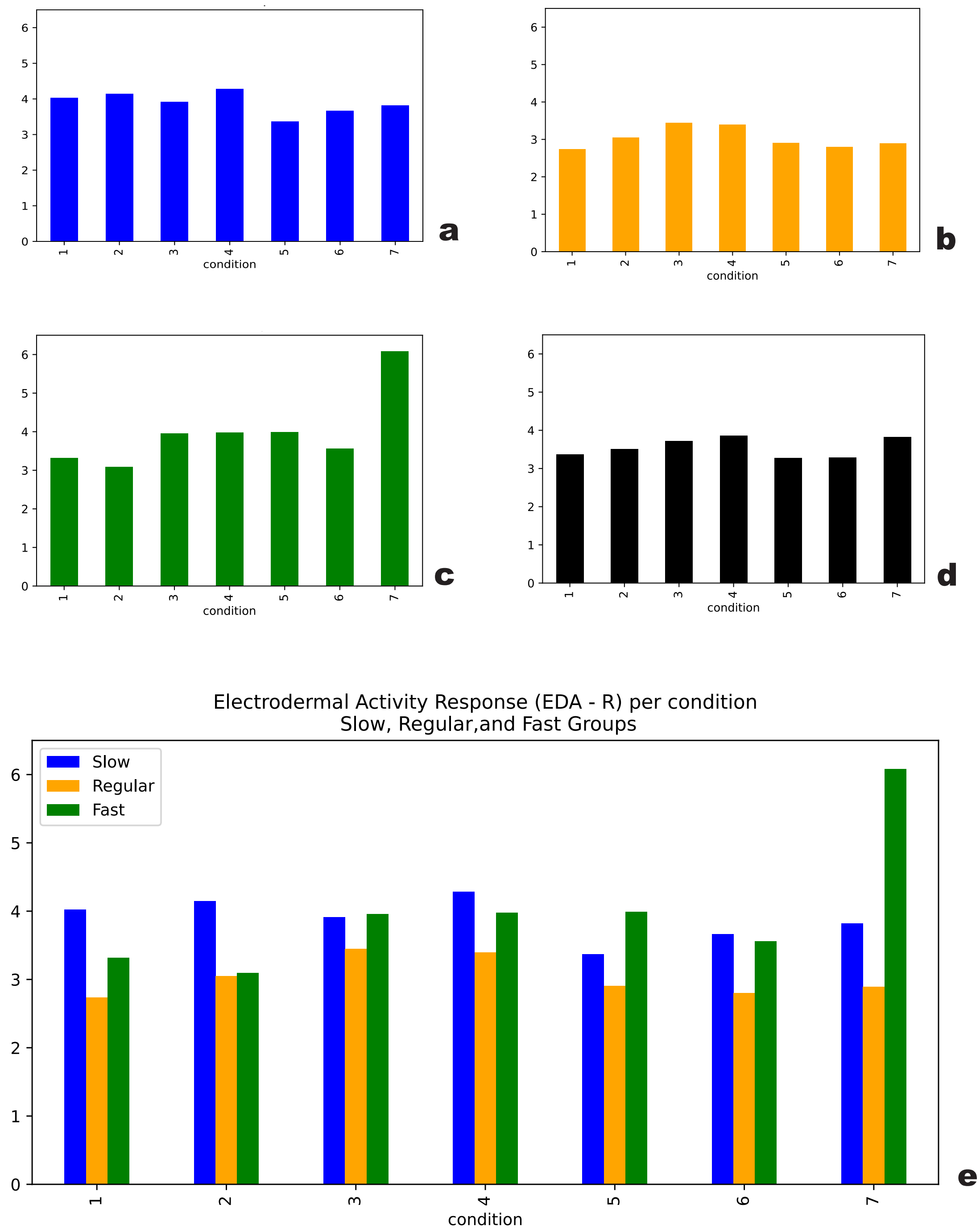


FIG II. 25
Electrodermal Activity Response (EDA-R) relative change from baseline per condition.
a. Slow Group b. Regular group. c. Fast Group. d. All Participants. e. Comparison of Slow, Regular, and Fast groups.

in comparison [FIG II. 24e], we can see the distribution of the values and start identifying any patterns. Overall in the Regular group the values are a little higher than in the Slow and Fast groups. Additionally, there is some variation in the values but no distinct pattern other than the fact that the conditions involving both pressure and warmth (condition 2, 4, 6) in general provoke more arousal than the conditions producing only pressure (condition 1, 3, 5) with the exception of condition 1 for the Fast group, and condition 6 for the Regular group.

Interestingly, the comparison of the values in condition 7 (the control condition) shows that the increase in EDA levels is higher in the Fast group compared to the Regular group, and the increase in EDA levels is higher in the Regular group compared to the Slow group. The relationship between the EDA level values in the control condition is surprising as one would expect this relation between the groups to exist in all the haptic conditions but the control condition. Ideally, one would want the Fast group to be more aroused than the Regular group and the Regular group more aroused than the Slow group in all haptic conditions but the control condition, where one should expect to see more or less the same values in all groups. Such a pattern would confirm that the control condition acts indeed as a control and that the pace of haptic action is positively correlated with participants' arousal levels. Curiously, however, this is not the case, possibly for the reasons discussed earlier.

When comparing the fluctuation of the EDA response (EDA-R) given the average values for each of the haptic conditions for all participants [FIG II. 25d], we observe that the greater fluctuation (highest number of peaks) is again in condition 4 (with 3.86 number of peaks on average) which is the condition with the simultaneous activation of the cuffs producing both warmth and pressure. When comparing the fluctuation per group for the entire duration of the test (average for all seven haptic conditions), the Fast group is the highest, with 3.99 number of peaks on average, followed by the Slow group, with 3.88 number of peaks on average, followed by the Regular group with 3.03 number of peaks on average. When plotting all groups and all conditions in comparison, we observe that the Regular group registers slightly lower values [FIG II. 25e]. Aligned with the results of the EDA levels, we also observe in a clearer pattern that conditions 3 and 4 with the simultaneous activation cause higher EDA fluctuation than the rest of the conditions, and conditions with both stimuli combined also cause slightly higher arousal then those of only pressure.

When comparing the fluctuation in the EDA response (EDA-R), given the average absolute change from baseline (positive or negative difference from baseline values), for all participants for each of the different conditions, the condition with most fluctuations is condition 4 (3.86), and the next condition with the highest response is condition 3 (3.72)

[FIG II. 26d]. All conditions that have both pressure and warmth stimuli cause more EDA fluctuations than the conditions with the same pattern of actuation without warmth: Condition 2 (3.51) > Condition 1 (3.36); Condition 4 > Condition 3 (3.72); Condition 6 (3.287) > Condition 5 (3.282). When comparing the fluctuation per group for the whole duration of the test, the Regular group has the highest fluctuation, with on average 1.28 more peaks per minute than the baseline, followed by the Fast group (0.9), then by the Slow group (0.85).

Looking at the EDA response absolute change values, when plotting all groups and all conditions in comparison [FIG II. 26a-e], there is greater variation compared to the values of the exact EDA-R measurements [FIG II. 25a-e]. In the Slow and Regular groups there is a pattern of higher absolute change in fluctuation in the conditions of both stimuli rather than only pressure [FIG II.26a-b]. It is again interesting in the comparison of the absolute change in the EDA-R values that in the control condition the Fast group shows higher change than the Regular group, and the Regular group higher change than the Slow group. Overall the EDA-R absolute change values are more aligned with the relative change EDA-L values, suggesting that the EDA-R absolute change calculations are better indications of the participants' condition than the EDA-R absolute values.

To understand whether and how the impact of the sleeve changes through time, it is useful to know if the EDA levels in general increase or decrease within each of the conditions. To be able to know if the levels increase or decrease within individuals, I used linear regression, fitting a first degree polynomial line in the EDA data for each participant for each session. I chose to use a first degree polynomial so I could calculate the slope of the line, which would reveal whether the levels increase or decrease. After calculating the first degree polynomial for the data of each participant individually, I calculated the mean values for all participants of each group. I then created bar graphs showing the mean slope for each of the groups in comparison. As the slope values were small because of the large number of EDA data captured by the sensor per second, I multiplied the values by 100 for better readability of the graphs [FIG II. 27].

Looking at mean slope values, it is interesting to observe that on average participants in all three groups demonstrate decrease of EDA levels from the start to the end of the condition of haptic action in all of the conditions [FIG II. 27]. In the Slow group the decrease varies a great deal between the conditions, with conditions 1 and 5 having the highest decrease, and conditions 3, 6, and 7 having the lowest decrease. In the Regular group, the conditions show less variety in the levels of decrease, and the highest decrease is less than the highest decrease in the Slow group. Within the Regular group, conditions 2 and 7 show the least decrease.

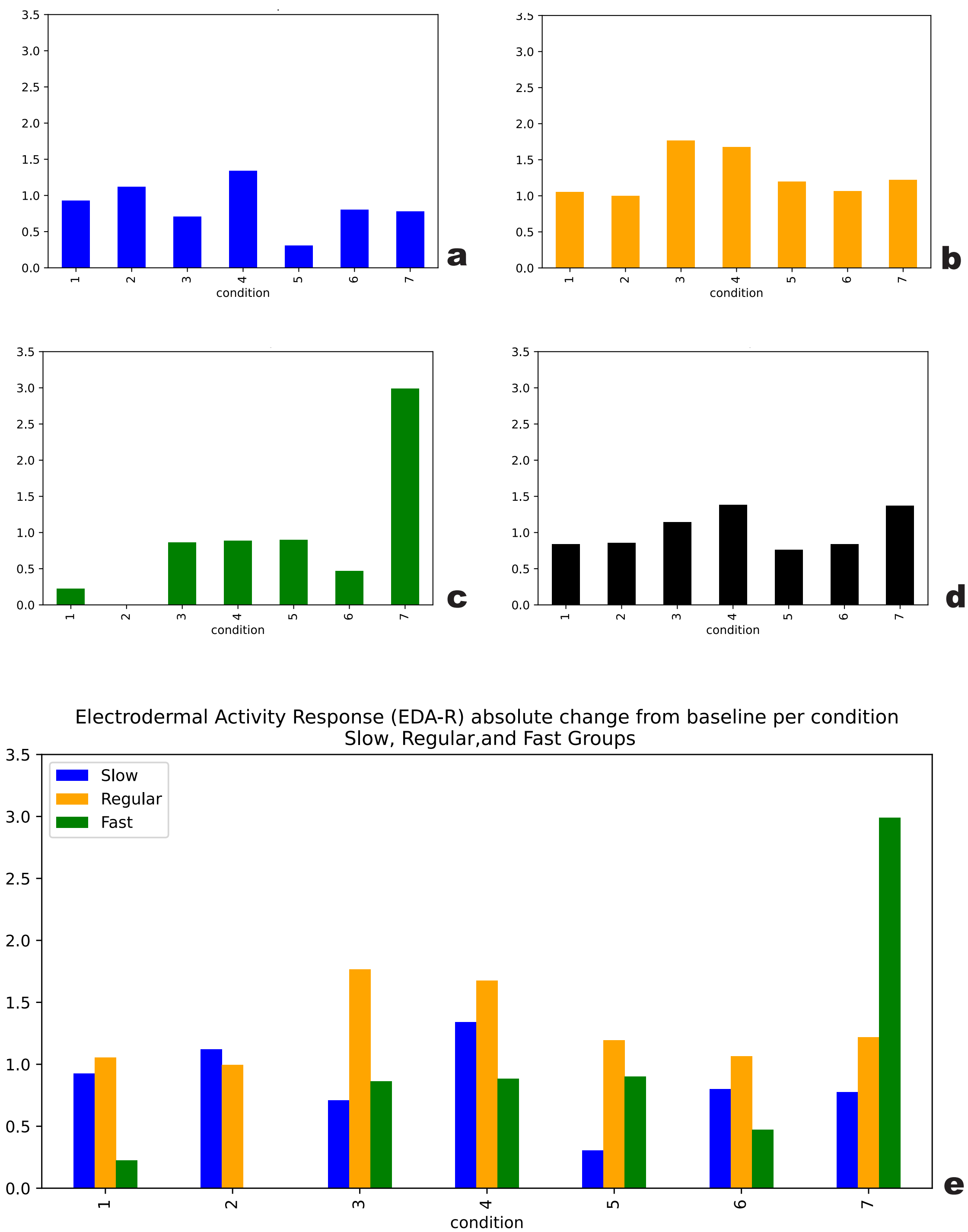


FIG II. 26
Electrodermal Activity Response (EDA-R) absolute change from baseline per condition.
a. Slow Group b. Regular group. c. Fast Group. d. All Participants. e. Comparison of Slow, Regular, and Fast groups.

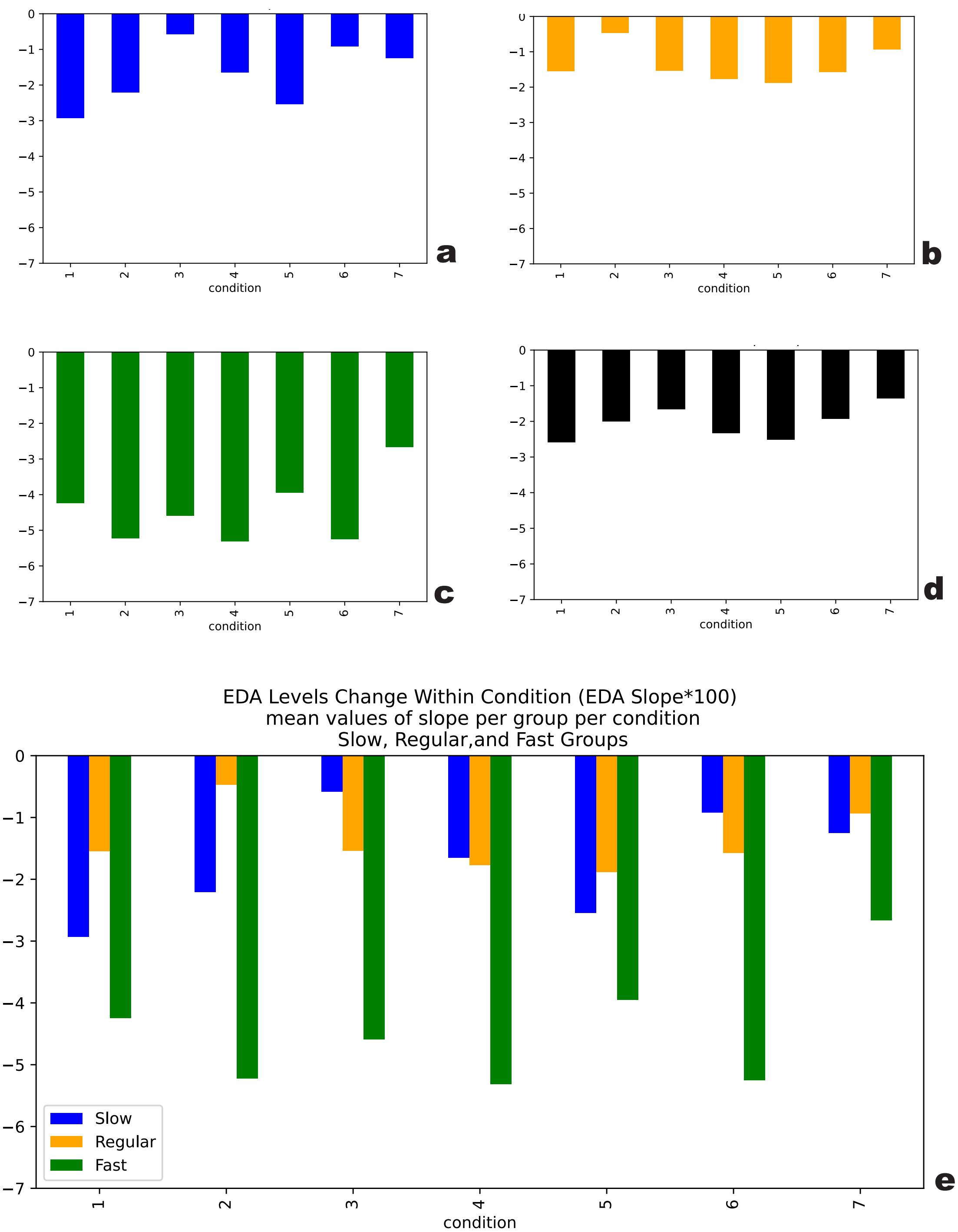


FIG II. 27
EDA levels change within condition (EDA Slope*100) mean values of slope.
a. Slow Group b. Regular group. c. Fast Group. d. All Participants. e. Comparison of Slow, Regular, and Fast groups.

When comparing the values of the Slow and Regular groups to those of the Fast group, it is surprising to note that the participants in the Fast group demonstrate more than double the decrease demonstrated by the participants in the Slow and Regular Groups (Mean Slope of Slow group: -1.72; Mean Slope of Regular group -1.38; Mean Slope of Fast group: -4.46) [FIG II. 27].

One can assume that participants' initial response, when the sleeve is activated at the beginning of each session, is much higher in the Fast group because the pace of haptic action is faster, and that it then drops significantly, once participants become used to the pattern. One can assume this explanation because the differences between the average levels as shown in the EDA-L relative change per conditions are small for most conditions, and interestingly, when the change differs noticeably, in conditions 4 and 5, it is the Regular group that shows the higher change, not the Fast group [FIG II. 24]. Similarly, the EDA-R absolute change does not exhibit important differences between the groups, except for the peculiar case of condition 7, where the Fast group exhibits much greater change [FIG II. 26]. Thus, one can only understand the double decrease in the slope of the EDA-L levels as a more dramatic change between higher and lower values within. It appears that on average, EDA levels in each condition begin higher and end lower in the Fast group compared to other groups.

Should we assume that the levels become elevated immediately when the haptic action begins and then subside? Or that the levels were elevated before the session, during the survey, and then dropped immediately after the condition started? We would be able to answer this question if the EDA level values for between the haptic conditions were calculated as well, or if we look at the EDA traces of the signals [see appendix]. To answer these questions, I calculated the mean values of relative change in EDA levels from baseline of each participant during each of the surveys following each of the haptic conditions (when the sleeve was inactive). Using these values, I then calculated the mean values of relative change in EDA levels from baseline for each of the three groups. I then plotted these values in a bar chart showing the mean relative change per condition for each of the three groups, followed by the mean change per survey. The chart has a two-bar configuration where the EDA relative change value for each condition is followed by the EDA relative change value of the corresponding survey, taken right after the condition [FIG II. 28].

In the graph showing the mean change values in EDA levels for each condition and survey side by side [FIG II. 28], the change in EDA levels is typically a little higher during the survey than in the preceding condition, with the difference being more prominent in the Fast group (with the exception of condition 3). In conditions 1 and 2 in the Slow group, and in condition 4 in the Regular group, the values are a little higher in the condition than in the succeeding survey, and in condition 3 in the Regular group, the values of the condition and survey are equal. Interestingly, condition 7 (control) follows a similar pattern with the rest of the conditions with the exception of the fact that it is the only condition in the Fast group where the value of the condition is slightly higher than the value of the succeeding survey.

Better insights are offered by the values of the EDA slope, showing the change of EDA levels (increase or decrease) within each condition and its succeeding survey. In bar charts, I plotted side by side the slope values of the EDA levels for each condition and its succeeding survey [FIG II. 29]. The results are exciting, as they show a clear pattern of decrease during the haptic conditions and increase during the succeeding surveys. In addition, the amount of decrease during the conditions, in the Slow and Regular groups, is typically greater than the amount of increase during the succeeding surveys. This pattern is especially obvious in the Slow group, with the exception of condition 3. Such a pattern shows that the relaxation that happens during the activation of the sleeve has a lasting impact on participants' affective state -- if we subtracted the amount of increase from the amount of preceding decrease, the level would still remain lower than it was than before the condition.

Comparing the different conditions based on the EDA levels change (slope) during each conditions and the succeeding survey [FIG II. 29], we observe that for the participants in the Slow group, conditions 2 and 4 are the most effective in reducing arousal levels, whereas for the participants in the Regular group, conditions 3 and 6 are the most effective in reducing arousal levels. For the participants in the Fast group, the amount of increase and decrease is much greater than that of the other two groups, showing that the sleeve with a fast pace of haptic action has a more significant impact in the change of EDA levels during the condition and immediately after. Also, for the participants in the Fast group, the amount of increase of the EDA levels is on average approximately equal to the amount of increase immediately after the completion of conditions, showing that the change of arousal levels is intense but brief. It seems that the fast pace of haptic action, in the long term has neither relaxing nor an arousing effect, but that the effect rather "balances out" [see appendix for patterns of the raw signal].

Seeing the pattern of the levels of change in condition 7 (control) [FIG II. 29], it seems that wearing the sleeve when it is not activated does not have a very different physiological impact on participants as it does when it is activated. However, contrary to most of the rest of the haptic conditions the amount of decrease during the control condition is the

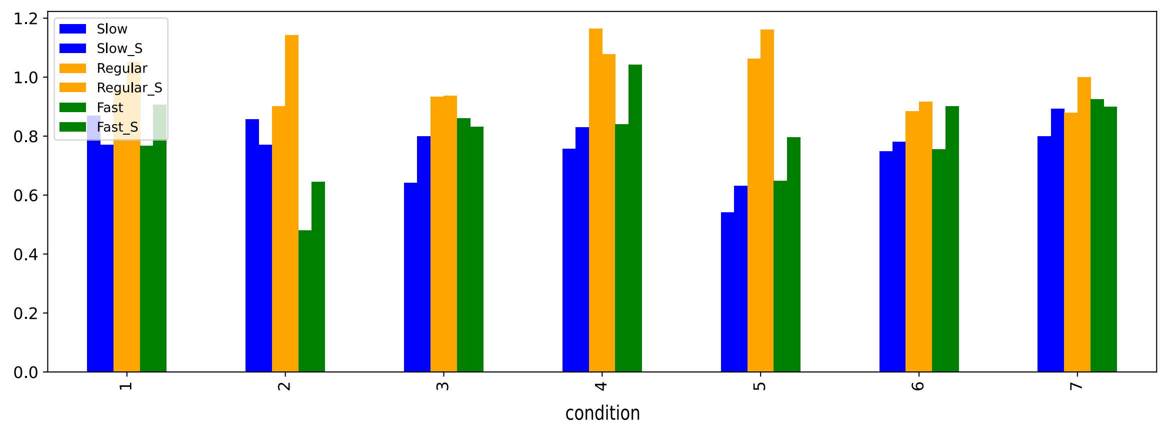


FIG II. 28
Electrodermal activity levels (EDA-L) relative change from baseline per condition and suceeding survey. Slow (blue), Regular (yellow), and Fast (green) groups.

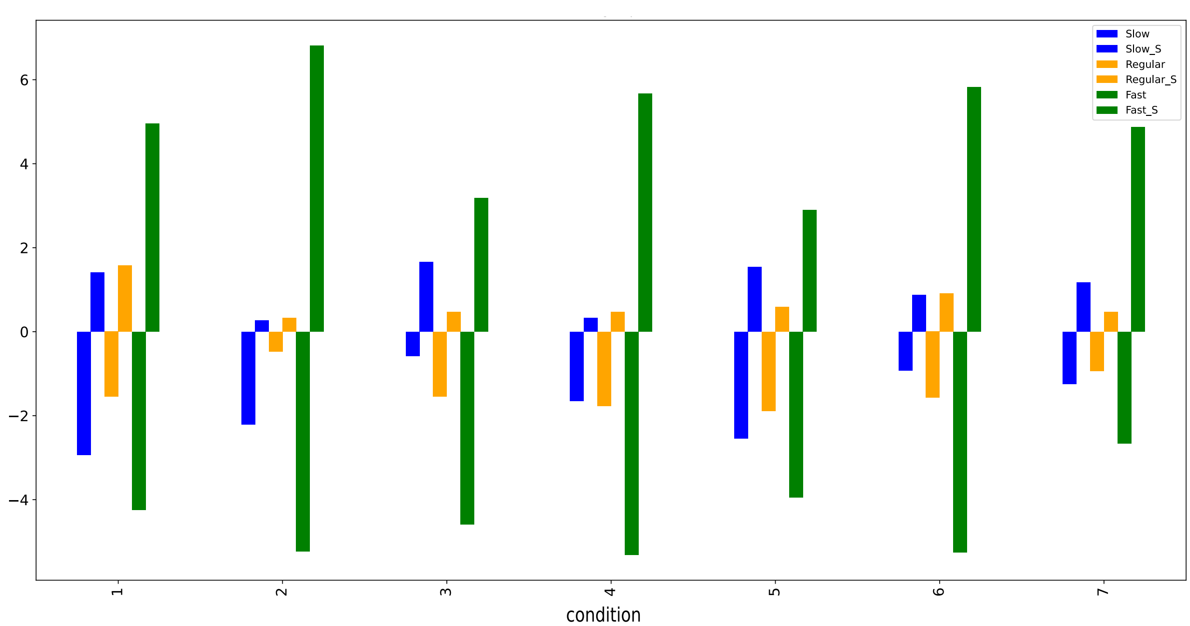


FIG II. 29
Electrodermal activity levels (EDA-L) change (slope) within each condition and within each succeeding survey. Slow (blue), Regular (yellow), and Fast (green) groups.

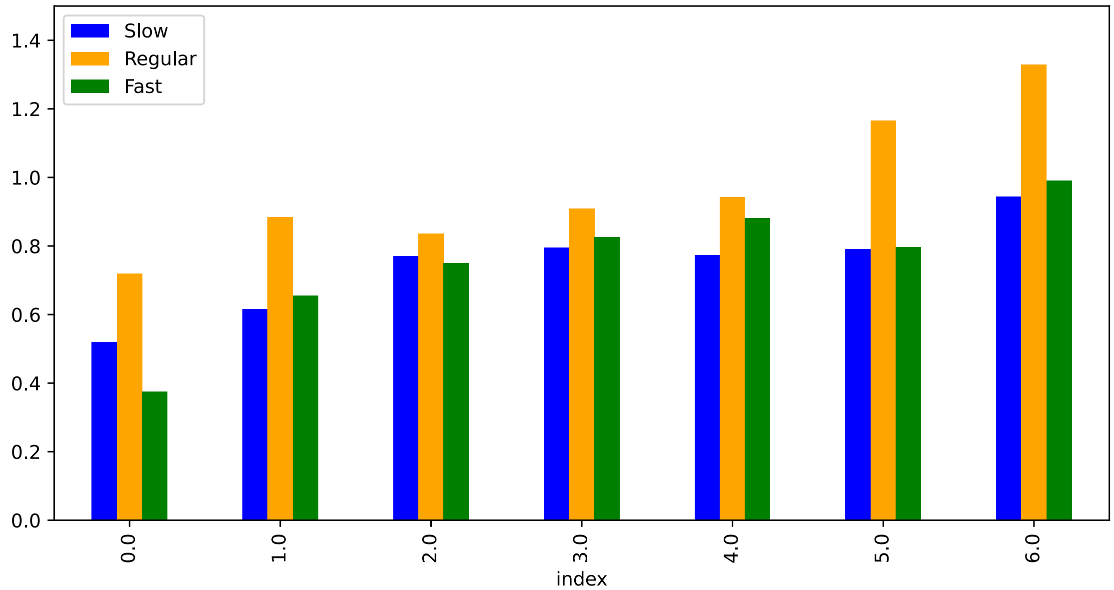


FIG II. 30
Electrodermal activity levels (EDA-L) relative change from baseline per index (true order). Slow (blue), Regular (yellow), and Fast (green) groups.

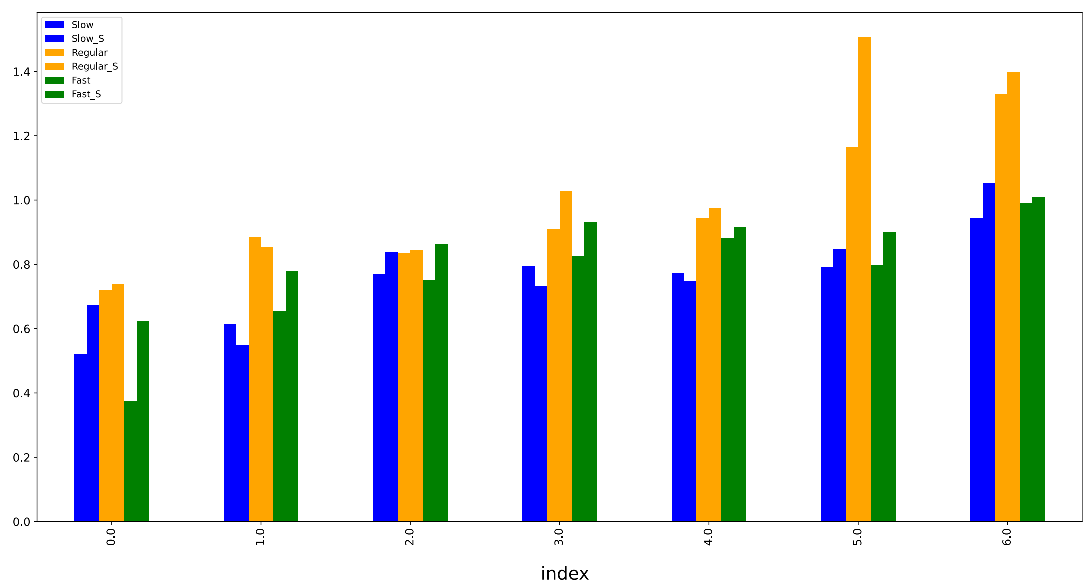


FIG II. 31
Electrodermal activity levels (EDA-L) relative change from baseline in each condition and succeeding survey per index (true order). Slow (blue), Regular (yellow), and Fast (green) groups.

same or smaller compared to the amount of increase of the succeeding survey. Should one assume that the sleeve has a physiological impact because of its materiality and feeling around the forearm, even without the pressure and warmth sensations? Should one assume that there is a lingering warmth and pressure sensation or some kind of illusory after-effect from the previously experienced conditions? The analysis of participants' interviews will provide more information regarding any placebo or other effects of the control condition.

Another way to obtain insights into how the impact of the sleeve changes over time is to visualize in sequence the data from the first condition in time experienced by participants to the last condition in time experienced by participants (in the order defined by the randomized sequence) [FIG II. 30 - 35]. Seeing the response to the conditions in the sequence they were actually experienced provides information regarding the overall impact of the sleeve through time (regardless of the conditions but depending on the pace of haptic action). Because conditions do not radically differ -- they all follow a rhythmic pattern or pressure and/or pressure and heat based on the breathing cycle -- one should expect some common patterns regardless of the specific conditions.

When collecting the study results, I kept track of the true sequence of conditions that each participant experienced and stored the variable as an array of indexes from 0 for the first condition to 6 for the last condition. I was then able to calculate the mean values for each participant and for each group per index instead of per condition. When the mean EDA-L relative change values are plotted for each group, as calculated from the mean EDA-L relative change values for each participant [FIG II. 30], one can notice a clear pattern: the level of participants increases consistently from the first to the last experienced condition. The increase is exhibited in the mean values of participants of all three groups, with the levels of the Regular group being slightly higher than the other two, especially in the last two conditions. The increase in the Regular group presents a clearer pattern of consistent increase with higher values, although the other two groups also exhibit a small increase overall from first to last conditions.

How can the difference between the Regular group and other two be explained? Is it an indication of a more "consistent" physiological response to the "regular" pace of the sleeve? In any case, the results reveal that participants' EDA levels (EDA-L) increase overtime during the study, more or less depending on the group. This fact could possibly be attributed to the participants' arms becoming "sweatier" over time, although this would not explain why the Regular group demonstrated higher increase than the other groups. When plotting and comparing the mean values of the EDA response (EDA-R) of the participants of the three groups in the true sequence they experienced the conditions (per index), the pattern of almost linearly increasing values that we emerges in the EDA level values does not emerge [FIG II. 46 - 47].

The EDA-R mean values per index (true order of conditions) show a pattern closer to a waveform, with alternating peaks and valleys [FIG II. 32 - 33]. Such a pattern might be coincidental or it might have implications regarding participants' physiological response. Could one assume that there is a high and low peak in the emotional response and that when the physiological response saturates, the body returns to each baseline? To obtain a better picture of participants' levels throughout the study, I plotted the mean values of EDA -L change (slope) from baseline per group for each condition in the true sequence these were experienced [FIG II. 34]. Here one can see the EDA-L levels change values (slope) of the conditions and surveys side by side with no significant difference between them but progressively decreasing during the study, especially for the Regular group.

To obtain a better picture of the change of levels during and after the conditions, and to see how the change is affected by the duration of the study, I also plotted the values corresponding to the slope of the EDA levels based on the true order in which the conditions and the succeeding surveys were experienced [FIG II. 35]. In the bar graph, one can notice a progressive decrease in the Slow and Regular group during the first 5 haptic conditions, with the amount of decrease during the haptic conditions being greater than the amount of increase in the post-condition survey. One can also notice a change in the response in the last two conditions where the amount of decrease during the condition and amount of increase in the succeeding survey are of approximately equal or greater amount.

In the graph showing the slope of EDA levels per condition and succeeding survey in the true sequence they were experienced [FIG II. 35], in the Regular group the absolute values of positive and negative slope for the condition and survey progressively increase until the fourth condition and then decrease. In the Fast group, in all sessions the amount of decrease during the condition and the amount of increase of EDA levels during its succeeding survey are approximately equal. Here it is worth wondering again if the bell shapes of increase and increase in the Fast group is a reflection of a physiological saturation towards a sensation, where a sensation peaks at its maximum limit of perceptual sensitivity and then slowly returns to baseline. If that is the case, one should perhaps expect to see, if the study were extended in time, a bell shape forming in the other two groups as well - the difference being between the Slow, Regular and Fast groups, that the Fast group reaches its peak faster because the amounts of EDA increase and decrease

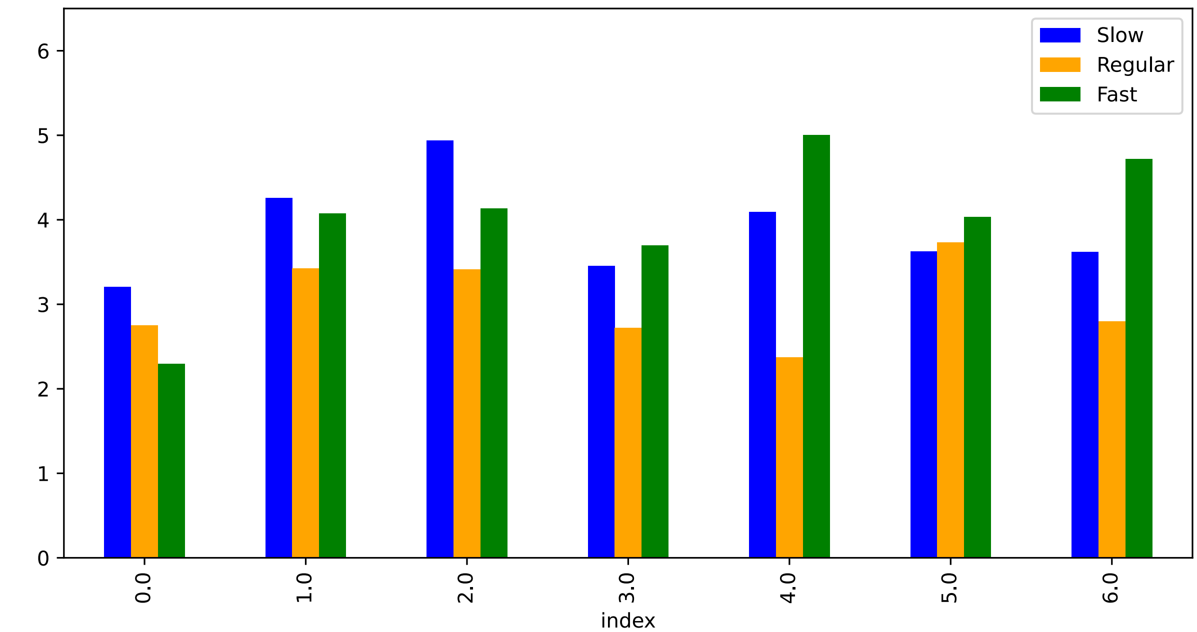


FIG II. 32
Electrodermal activity response (EDA-R) per index (true order). Slow (blue), Regular (yellow), and Fast (green) groups.

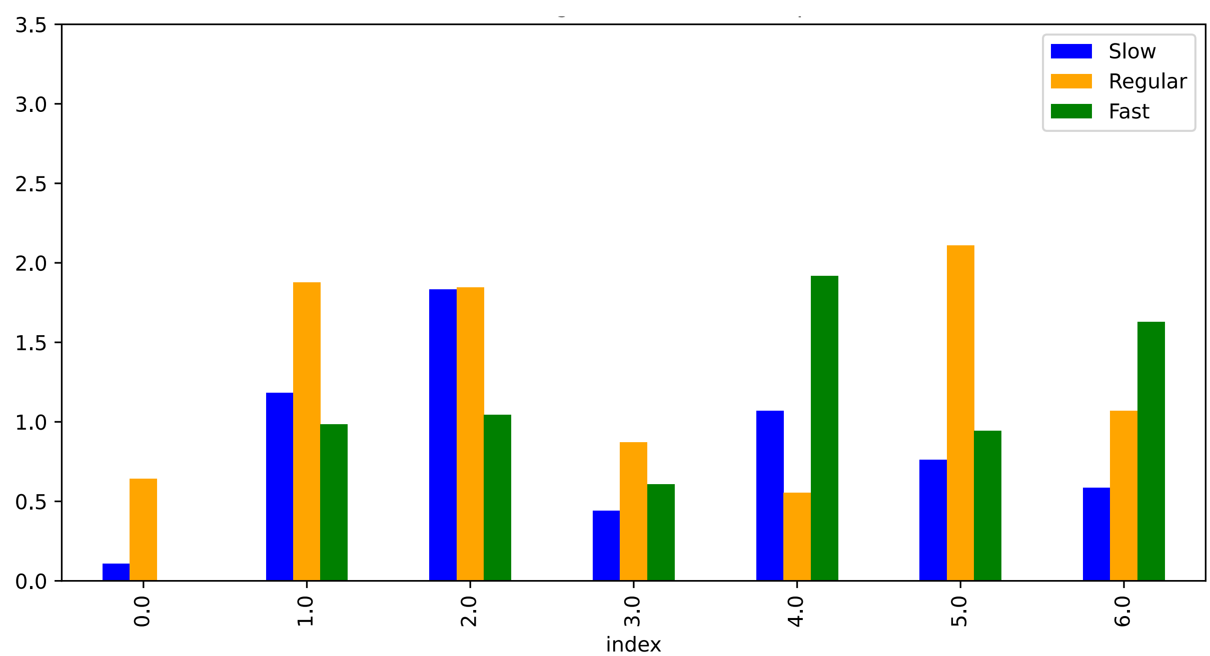


FIG II. 33
Electrodermal activity response (EDA-R) absolute change per index (true order). Slow (blue), Regular (yellow), and Fast (green) groups.

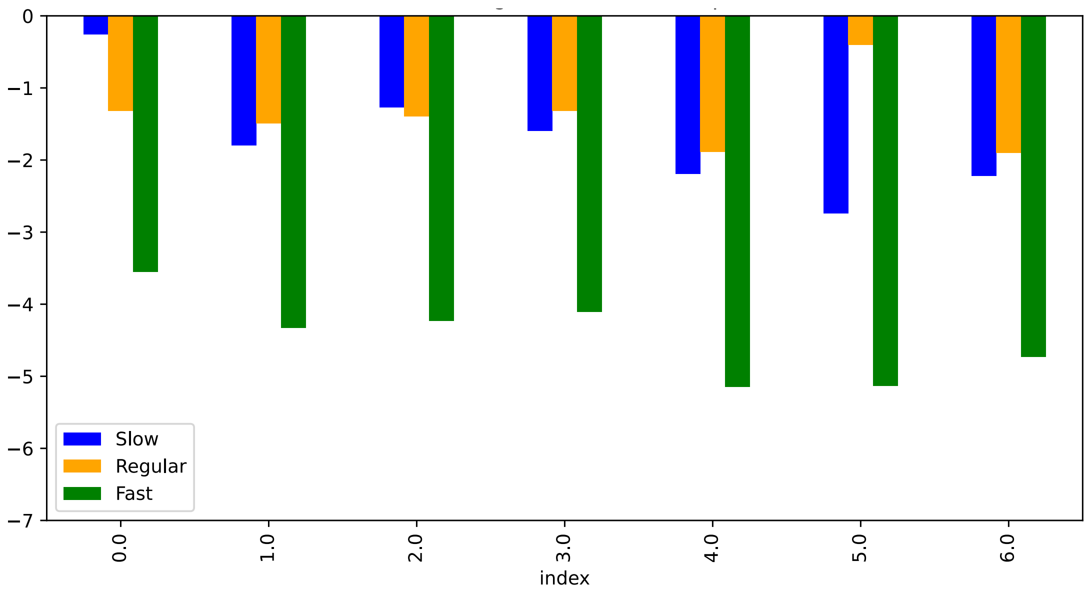


FIG II. 34
Electrodermal activity levels (EDA-L) change within condition (slope*100) mean values of slope per index (true order). Slow (blue), Regular (yellow), and Fast (green) groups.

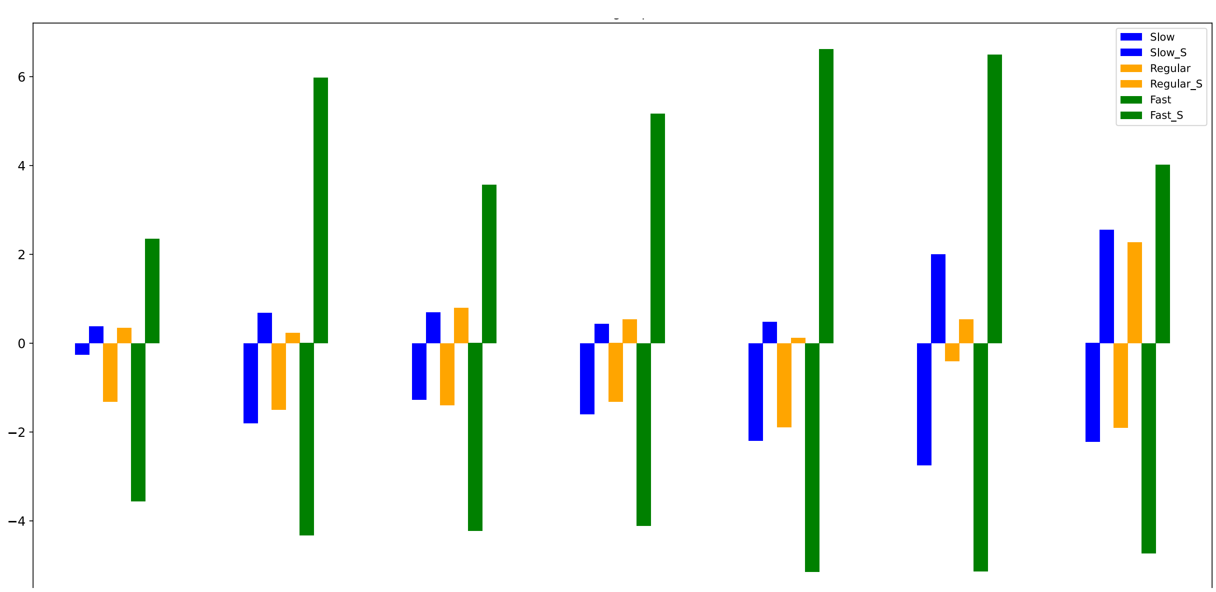


FIG II. 35
Electrodermal activity levels (EDA-L) change within condition and within each succeeding survey (slope*100) per index (true order). Slow (blue), Regular (yellow), and Fast (green) groups.

(slope) are greater than the other two groups.

Breathing Activity. For the Breathing Activity I used the E-Sense Mindfield Respiration sensor with a sampling rate of 5 values per second. The E-Sense Mindfield smartphone app did the low level processing calculating the values of breath per minute (BPM). I exported the BPM values of the baseline and the seven haptic conditions by matching the UI timestamps for the start and end of each condition with the sensor's timestamp. From the baseline phase I removed the first and last minute of the recorded data (keeping at least 5 minutes of collected data), to remove measurements during calibration and motion artifacts from removing the sensor. From the collected data, I calculated the average BPM for the baseline and for each haptic condition for each participant. I then calculated the percent relative change from baseline for each haptic condition of each participant using the following formula: (Condition BPM average / Baseline BPM average - 1) *100%. Following this calculation, I also calculated the mean for each condition of all participants' BR change in each group.

To have more accurate results, I excluded a few outliers from the data. To do so, I calculated the InterQuartile Range (IQR) for the average percent BR change for each group. The InterQuartlie Rage is equal to the difference between the third and first quartile values. The first quartile, denoted by Q1, is the median of the lower half of the data set. Thus 25% of the values in the data lie below Q1. The third quartile, denoted by Q3 , is the median of the upper half of the data set. Thus 75% of the values lie below Q3. Typically outliers are considered the values above the value of the third quartile with the added value of 1.5 IQR, and below the first quartile with the subtracted value of 1.5 IQR. Because of the small number of participants, I decided to include a larger range of values, thus I excluded values lying above the third quartile with the added value of 3 IQR (Q3 + 3 IQR) and values lying below the first quartile with the subtracted value of 3 IQR (Q1 - 3 IQ3).

The data excluded as outliers were those of two participants in the Regular group (ID 42 gender Female, Age 34; ID 21 gender Male, Age 30). The BR values of participant ID 42 were in more than half of the conditions lower than 6 BPM, possibly indicating that there was a bad sensor connectivity. The rest of the participants were within normal BR range (equal or above 8 and equal or below 25). When more than 4 of the conditions fell above or below the upper or lower range, all BR values from the participant were discarded. IQR was calculated separately for each of the three groups to ensure that individual group differences were maintained and not smoothed out. In the Fast group there were no values above or below 2 IQR from the first and third quartile as calculated for the specific group. In the Slow group, there were five values (values of five individual conditions) above or below 2 IQR from the first and third quartile, as calculated for the specific group.

To draw conclusions regarding the difference of BR change from baseline between the groups, I calculated the mean of the mean relative change from baseline per condition for each group. On average, participants in the Slow group exhibited a 4.79 % decrease in BR during testing, participants in the Regular group exhibited a 2.08% decrease in BR during testing, and participants in the Fast group, on average exhibited a 7.20% increase in BR during testing [FIG II. 36]. These results are aligned with my hypothesis, as I expected that a pace of haptic action slower than the relaxed breathing rate would lead to decreased BR, and a pace of haptic action faster than the relaxed Breathing rate would lead to increased BR. Demonstrating a positive correlation with the pace of haptic action, BR decreased in the Slow group and increased in the Fast group. The values of the Regular group in individual conditions lie between the other two groups, sometimes showing decrease (conditions 2,3,5,6) and sometimes showing increase (conditions 1,4).

When the values of the Regular and Slow groups that both on average demonstrated decrease during the haptic conditions are averaged together, the results show that the highest decrease overall in those groups was demonstrated in conditions that produced both warmth and pressure (haptic conditions 2, 4, 6) rather than pressure alone (haptic conditions 1, 3, 5). It is interesting to compare these results with the EDA results as conditions producing both warmth and pressure cause greater increase in EDA levels (EDA-L) [FIG II. 24] and EDA response (EDA-R) [FIG II. 25 - 26]. Conditions with simultaneous activation of the cuffs with pressure alone caused roughly twice the amount of decrease in BR than did conditions with sequential activation of the cuffs with pressure alone. Conditions involving simultaneous activation of the cuffs (conditions 3 and 4) caused about the same or less decrease on average compared to haptic conditions with sequential pressure and warmth. The conditions that caused the least decrease in BR were conditions with sequential activation of the cuffs involving pressure alone (conditions 1 and 5) [FIG II. 36].

When comparing the values per condition for the Fast group, one can observe that the haptic conditions with the highest increase are haptic conditions 3 and 4, which involve the simultaneous activation of all cuffs [FIG II. 36c]. In this group, there is no clear pattern regarding the effect of warmth and pressure combined or pressure alone. Given the results in EDA and BR combined, an interesting pattern emerges, demonstrating that the most effective conditions in causing BR changes are the conditions that also cause greater EDA changes. The results of the survey will determine how these changes affect the subjective perception

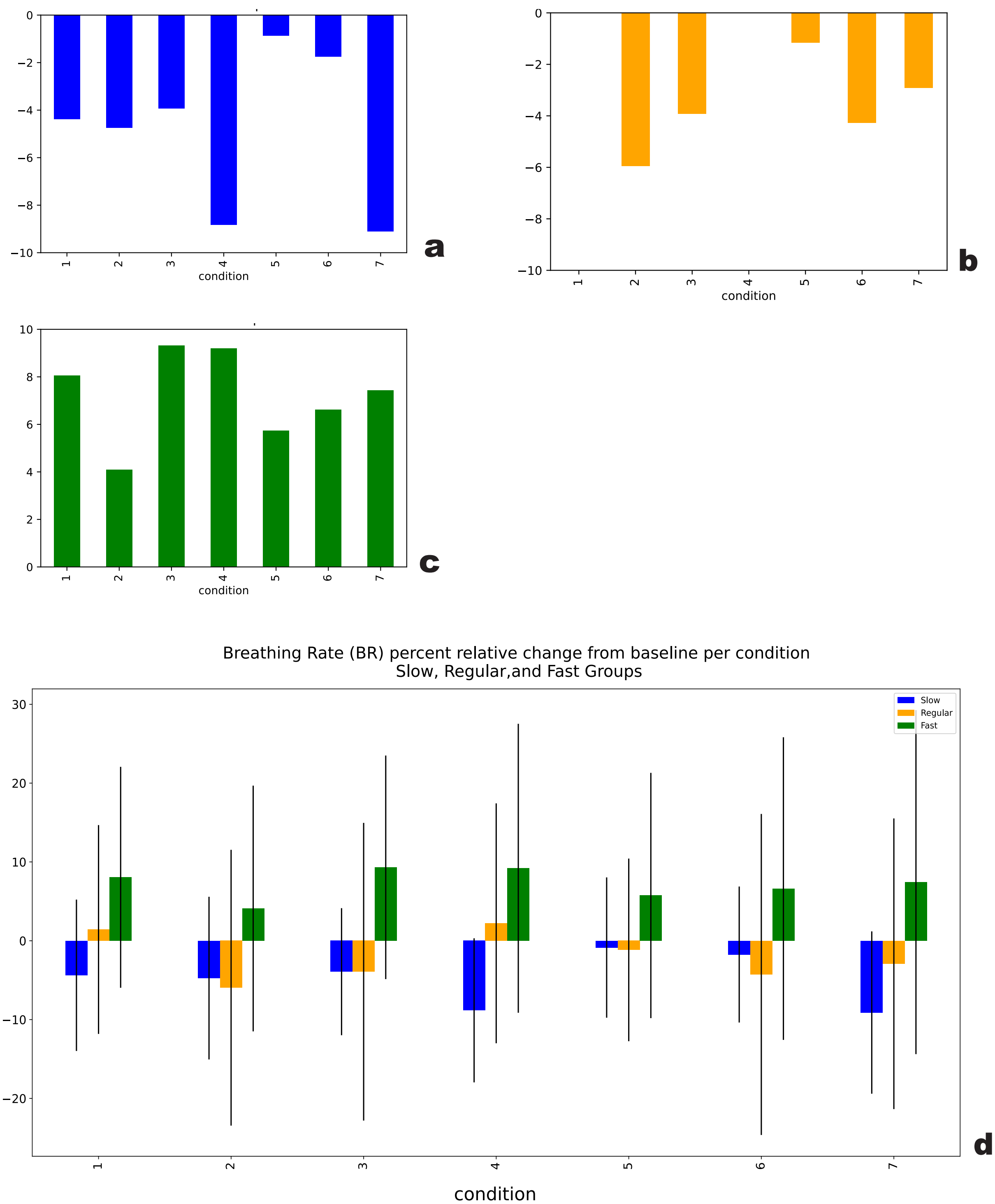


FIG II. 36
Breathing rate (BR) percent relative change from baseline per condition.
a. Slow Group b. Regular group. c. Fast Group. d. Comparisonn of Slow (blue), Regular (yellow), and Fast (green) groups.

of affective states. Does the sleeve produce a relaxation-in-action effect that increases the arousal levels due to the physical haptic action of the sleeve but lowers the breathing rate to produce a calm state? It is intriguing that the EDA levels seem to have a negative correlation to BR relative change.

When plotting the results for each haptic condition per group, one can obtain a better picture of the results in comparison and identify any emerging patterns [FIG II. 36d]. Seeing the results together, one can observe a "symmetric" response (above and below 0) between the Slow and the Fast groups: in general, the greater the decrease in the Slow group, the greater the increase in the Fast group. As hypothesized in this study, a pace of haptic action slower than the participant's relaxed BR decreased participant's BR more than haptic action equal to participant's relaxed pace. Observing this pattern, we see a trend of a positive correlation between the sleeve's pace of haptic action and the participant's BR. The response of the participants in the Regular group is interesting, as it varies between increase and decrease depending on the condition, showing greater variation than in the other two groups.[1]

Regarding the control condition (haptic condition 7), in the results of the BR data one can observe again the same surprising peculiarity as in the EDA results. Although typically in control conditions one expects the values to be more or less equal among groups, assuming that because of the absence of haptic action participants do not have a significant decrease or increase in BR, the results defy those expectations. Similarly to the EDA analysis, the comparison between the groups shows what would be the ideal expected difference between the groups in the rest of the haptic testing conditions where participants actually experience the haptic action of pressure with or without warmth. The Slow group shows on average a 9.10% decrease in BR from the baseline; the Regular group shows on average a 2.91% decrease in BR from the baseline, and the Fast group shows on average a 7.43% increase from baseline.

When analyzing the EDA data, one hypothesis I made is that during condition 7 (control) participants may be restless as a result of doing nothing. Although this might be possible, the BR results show that there is a pattern correlated with the pace of haptic action produced in the rest of the haptic conditions. If we were only to assume restlessness, the values would likely all be high in the BR data showing an anxious response, and probably would not follow a clear pattern, as is the case now. One thus need to assume a different reason to explain this result. Another

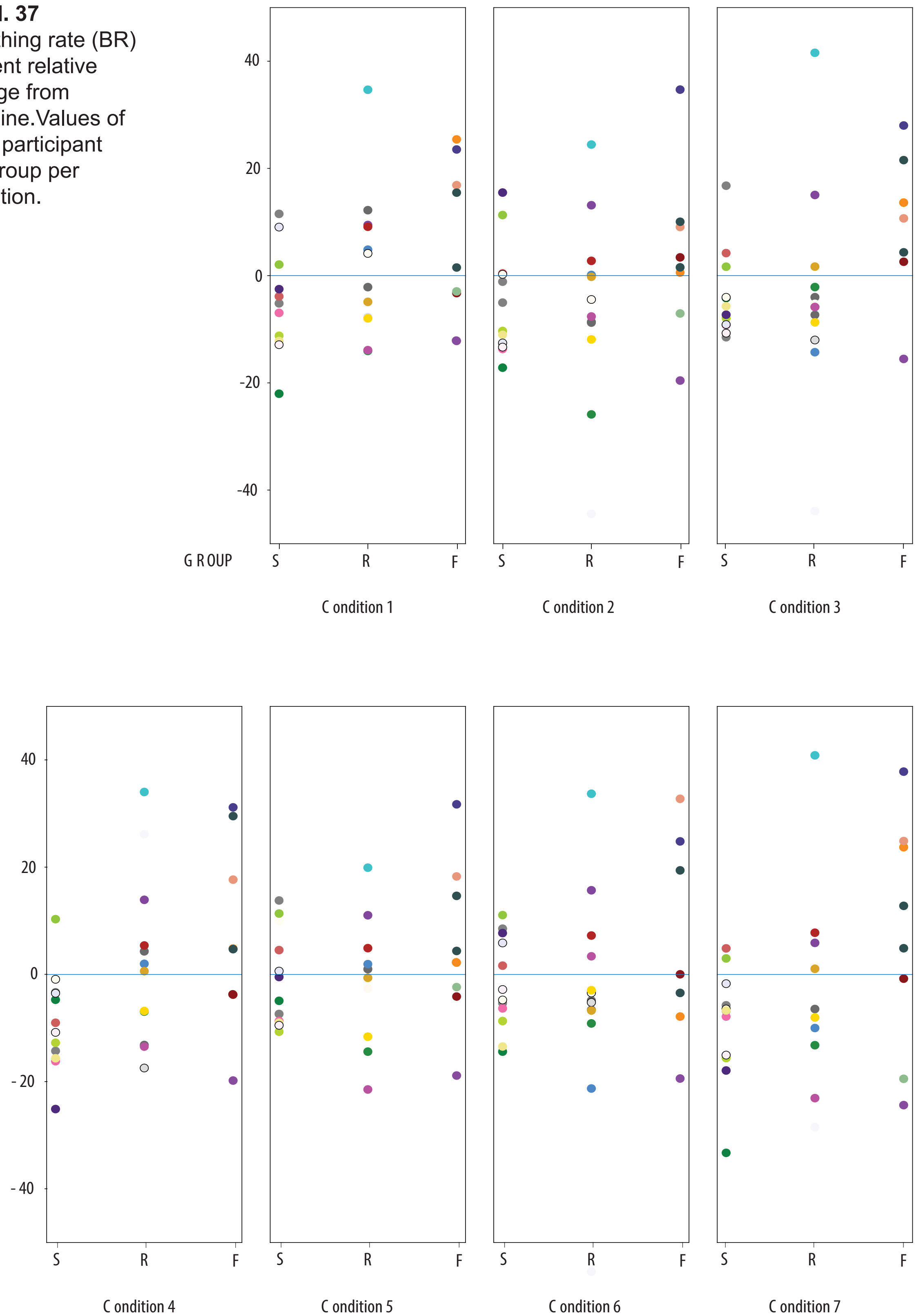
---

1 If the upper and lower limit that define the outliers of the study are reduced, then all average responses of the Regular group per condition demonstrate decrease.

factor to take into account is that condition 7 is randomly set among the other conditions and only lasts 1.5 minutes. This means that there is possibly an after effect from the previously tested conditions. Although it is possible that there is an after effect in all the conditions, condition 7 is special because the participant is doing nothing; it is thus possibly the only condition where the body can relax and allow the previous “bodywork” to express its effects on the nervous system.

When error bars of one standard deviation are added into the BR graphs, once can observe that overall there is a wide range of the BR change values among participants [FIG II. 50d]. To obtain a better picture of the range of BR values and their distribution, I created a scatter plot depicting the percent relative BR change from baseline for each participant [FIG II. 37]. The values in the different haptic conditions are depicted with a distinct color for each individual participant in order to make clear any emerging patterns or individual peculiarities. In the scatterplots, when visually comparing the concentrations of value in the three groups, one can observe that more participants show a decrease in BR in the Slow group than in the Regular group and that the values of the Fast group are more concentrated above zero, showing an overall increase in BR. One can also observe that the values in the Regular groups are more spread out than in the other two groups. Although the trends are aligned with the study hypothesis, more studies would be needed to arrive at a more concentrated distribution of the data, leading to statistically significant conclusions [FIG II. 37].

FIG II. 37
Breathing rate (BR) percent relative change from baseline.Values of each participant per group per condition.



3.1.4b SELF-REPORTED DATA ANALYSIS

Perception of sensations produced by the sleeve's haptic action. As discussed in the context of the first study on the sleeve [chapter 3.1], one parameter to investigate further is the impact of the pressure and warmth sensations when applied together or individually. The haptic conditions implemented in this second study are either only pressure (conditions 1,3,5) or pressure and warmth combined (conditions 2,4,6). For each condition that produces only pressure, there is an equivalent condition that produces pressure and warmth. Thus, conditions 1 and 2 are of the same haptic pattern (full cycle sequential activation), conditions 3 and 4 are of the same haptic pattern (full cycle simultaneous cuff activation), and conditions 5 and 6 are of the same pattern (half cycle sequential cuff activation) [FIG II. 18].

One of the questions that arose in the first study [chapter 3.1] was to what extent the impact of the sleeve was subliminal. Another question was to what extent the participants actually felt the programmed sensations and where on the forearm they felt them more intensely. To address these questions in the second study I integrated questions in the UI survey pertaining to the perception of the warmth and pressure sensations. After experiencing a haptic condition, participants were first asked in the UI survey if they felt a warmth sensation and/or a pressure sensation. If they replied positively for either of those sensations, a window with sliders appeared on the screen with a question pertaining to the intensity of each felt sensation along the forearm, and a question pertaining to degree of pleasantness of the each felt sensation [FIG II. 21-22].

As an indication of whether participants perceived the programmed sensation or not, or experienced a placebo effect, I first analyzed participants' responses to the simple questions in the survey: Did you feel a pressure sensation? and Did you feel a warmth sensation? To make comparisons between groups, because the number of participants among the groups was unequal, I calculated the percentage of the participants in each group who provided a positive response (instead of a negative response). I then plotted one set of bar graphs for each of the three groups. Each set of bar graphs shows the percentage of participants that responded positively to the sensation of warmth in red-colored bars for each of the seven conditions, and the percentage of participants that responded positively to the sensation of pressure in blue-colored bars [FIG II. 38].

Observing the percentage of participants that felt warmth and pressure per condition per group, one can notice that when experiencing the haptic conditions including both warmth and pressure (conditions 2, 4,

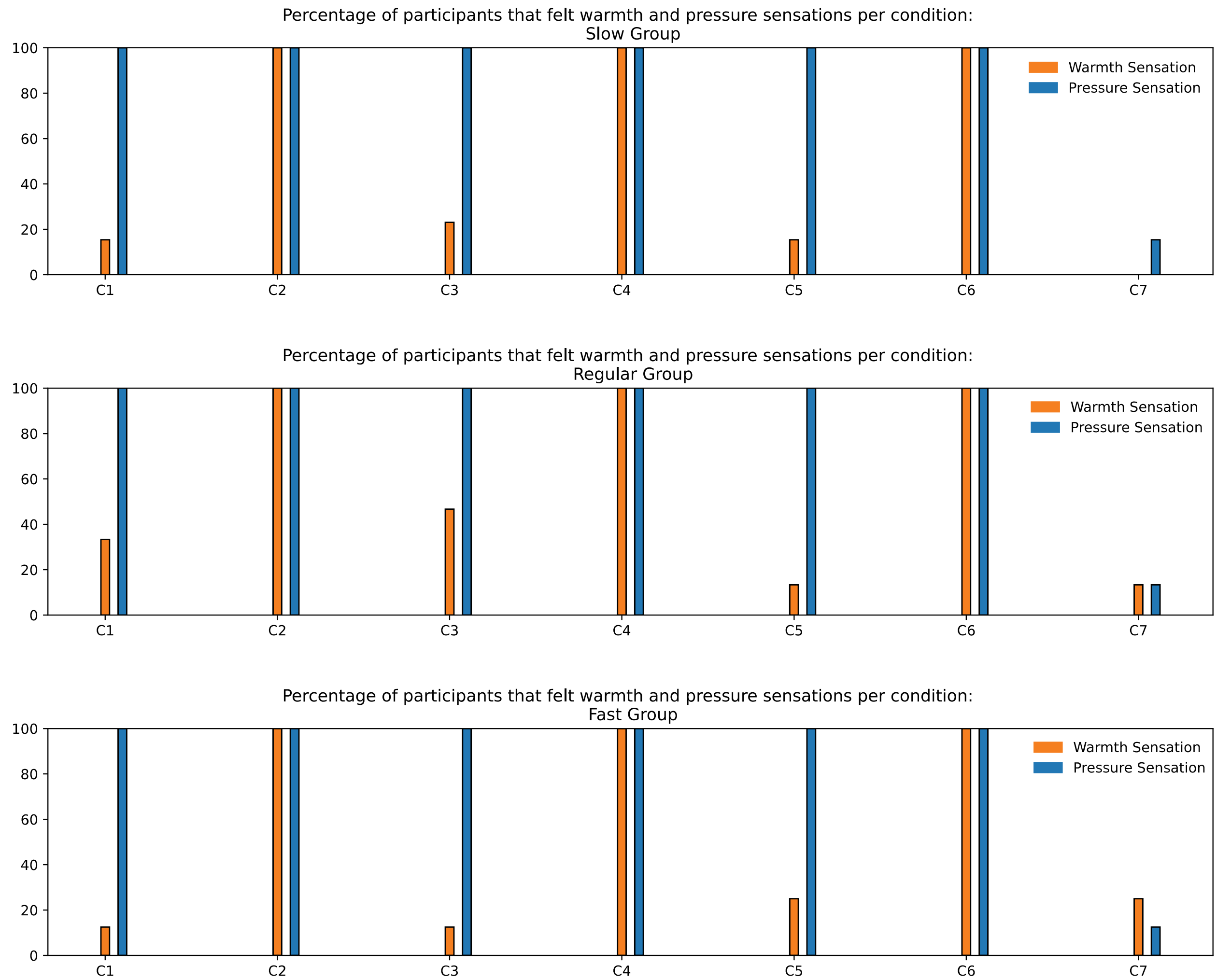


FIG II. 38
Percentage of participants that felt warmth (orange) and pressure (blue) sensations per condition. Top: Slow group. Middle: Regular group. Bottom: Fast group.

6), 100% of the participants responded that they felt both a warmth and a pressure sensation. This result is important for a few reasons. The result shows that the sleeve was functioning properly. The result also shows that any impact from the sleeve was not subliminal, as participants were aware of the sensations. The result also show that participants were able to distinguish between the two sensations and that one sensory feeling did not mask the other (which would be the case if, for example, the pressure was overwhelming and the warmth barely felt). Finally, the result shows that in the conditions comprising both pressure and warmth, the perception of those two sensations did not depend on the pattern of haptic action, as all participants in all three of the conditions equally identified the two sensations [FIG II. 38].

Regarding the haptic conditions that included pressure and not warmth (conditions 1, 3, and 5), it is interesting to observe that 100% of the participants reported feeling pressure but also a small percentage of the participants reported feeling warmth. More specifically, of all the participants in the study, 20% felt warmth in the first condition, 27% felt warmth in the third condition, and 17% felt warmth in the fifth condition. In the control condition (condition 7) including no warmth or pressure, 12% of the participants felt warmth and 13% of the participants felt pressure [FIG II. 38]. Three reasons may explain these results. The first reason is a possible psychological carryover effect from previously tested conditions: participants were feeling the heat or pressure and then had the false impression that they were still feeling it. The second reason is that even if the sleeve was not actively doing anything, it was nevertheless wrapped around the arm and could thus create the impression of very slight warmth and pressure.

After participants responded in the UI that they experienced a feeling of pressure or warmth, an additional question with a slider would appear asking them to rate the intensity of pressure (if pressure was felt), and the intensity of warmth (if warmth was felt) on each of the areas covered by the five sleeve cuffs. The slider knob could be placed anywhere on or between “1- MIN” and “5- MAX” and the intermediate markers 2, 3, and 4. The stored values ranged from 0 to 100 (0 corresponding to ‘MIN’ and 100 to ‘MAX’) [FIG II.21-22]. To compare the values for each cuff per condition and per group, I plotted the values for each cuff side-by-side for the subjective intensity of pressure [FIG II. 39], the subjective intensity of warmth [FIG II. 40], and for the subjective intensity for both pressure and warmth combined [FIG II. 41]. In the graph with the combined sensations [FIG II. 41], warmth is shown in red bars and blue is shown in blue bars. For each condition, five red and five blue bars are grouped together, corresponding to each of the cuffs. Reading from left to right, the first bar in the group represents the felt intensity for the cuff near the wrist (cuff I), and the fifth bar the cuff closer to the elbow (cuff V).

Comparing the subjective intensities of the warmth and pressure sensation per group [FIG II. 39-41], it is interesting to observe how the perception of intensity for each cuff changes depending on the haptic condition of the sleeve. In the haptic conditions with the sequential activation of the cuffs (haptic conditions 1, 2, 5, 6), the first cuff (closer to the wrist) is on average perceived as the one producing the most intense pressure sensation. The pattern is very clear, with the first cuff being ranked significantly higher than all the rest of the cuffs in terms of pressure. In the haptic conditions involving sequential activation of the cuffs producing pressure and warmth sensations (haptic conditions 2, 6), with the exception of haptic condition 2 for the Fast group, the intensity of warmth is also ranked the highest of all cuffs, although the difference from the rest of the cuffs is not as significant as in the case of pressure evaluation.

In the haptic conditions with sequential activation of the cuffs (haptic conditions 1,2,5,6) — in all cases except the haptic condition 2 in the Fast group -- the perceived intensity of the sensations is increased in the first cuff, gradually subsides in the second and third cuff, and becomes gradually more intense again in the fourth and fifth cuff, closer to the elbow. Thus the data shape a form of an asymmetric, left-sided valley with values associated with the first and last cuff being higher than the ones in the middle, and with the start of the valley showing a higher rise than at the end. Participants in the sequential patterns of haptic action felt the sensation more intensely at the start of the sequence near the wrist; the feeling lessened and then became more intense at the end of the sequence, near the elbow (as the haptic action started at first cuff and ended at the last cuff, and then started again at the fist cuff, continuing the sequential activation recursively).

It is interesting to compare this observed left-sided asymmetric valley pattern of felt intensity exhibited by the haptic condition of sequential activation of the cuffs with the almost symmetric bell shape of the values of perceived warmth and pressure intensity in the haptic conditions with simultaneous activation of the cuffs (haptic conditions 3, 4). The bell shape is especially clear in the graph of haptic condition 4 in the Slow group, where the perceived intensity of pressure and warmth in the middle cuff is the highest and the intensity towards the two ends of the sleeve subsides. A similar shape, albeit not as perfectly symmetric, is presented in haptic conditions 3 and 4 in the rest of the groups, with the exception of haptic condition 4 in the Fast group. What is intriguing in the comparison between the valley-shaped data of haptic conditions 1,2,5,6 and the bell-shaped data of haptic conditions 3 and 4, is the realization that the actual pressure and temperature in each cuff is exactly the same. Thus, interestingly, the patterns of haptic action significantly change the perceived intensity of the sensations [FIG II. 39-41].

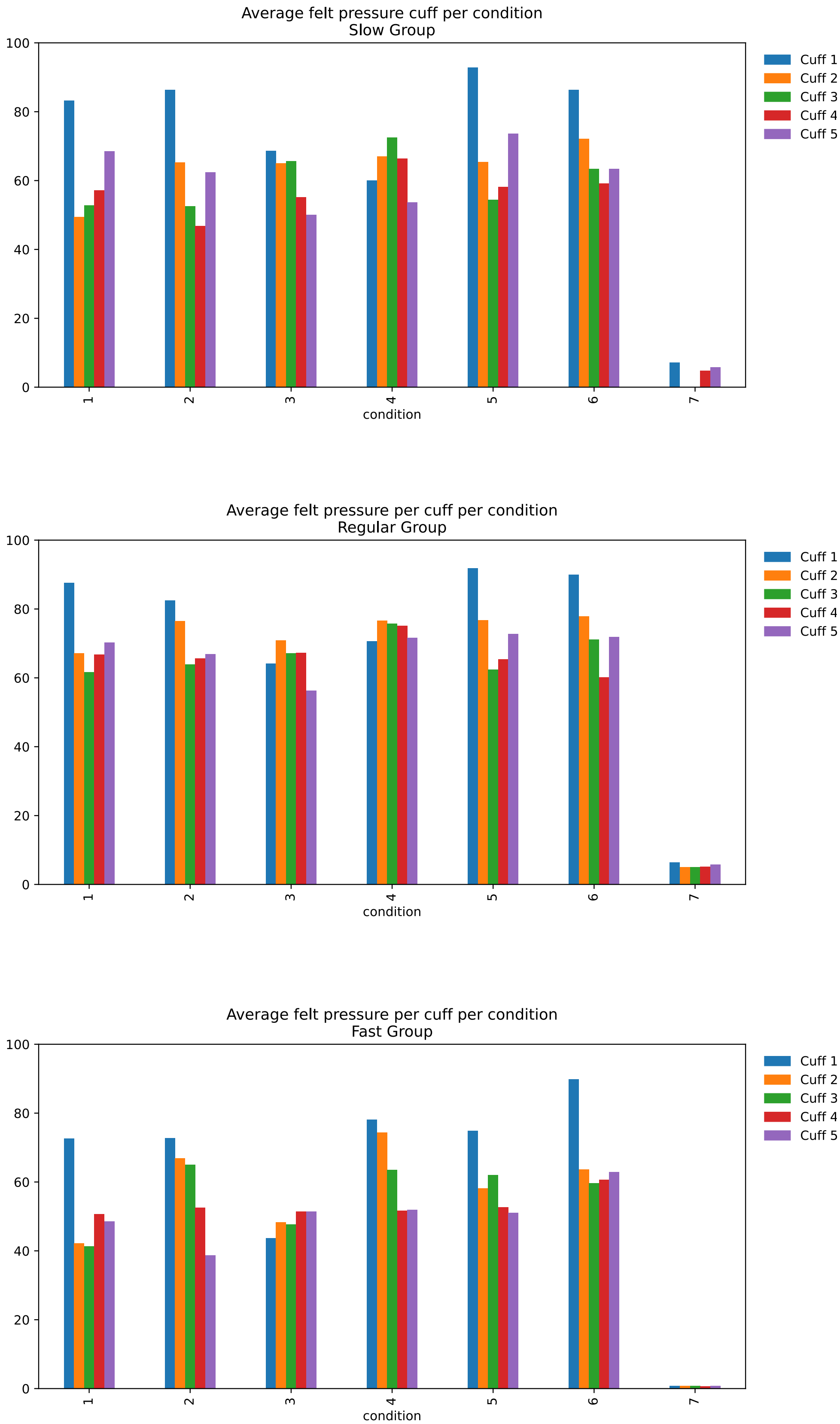


FIG II. 39
Average felt pressure per cuff per condition. Top: Slow group. Middle: Regular group. Bottom: Fast group.

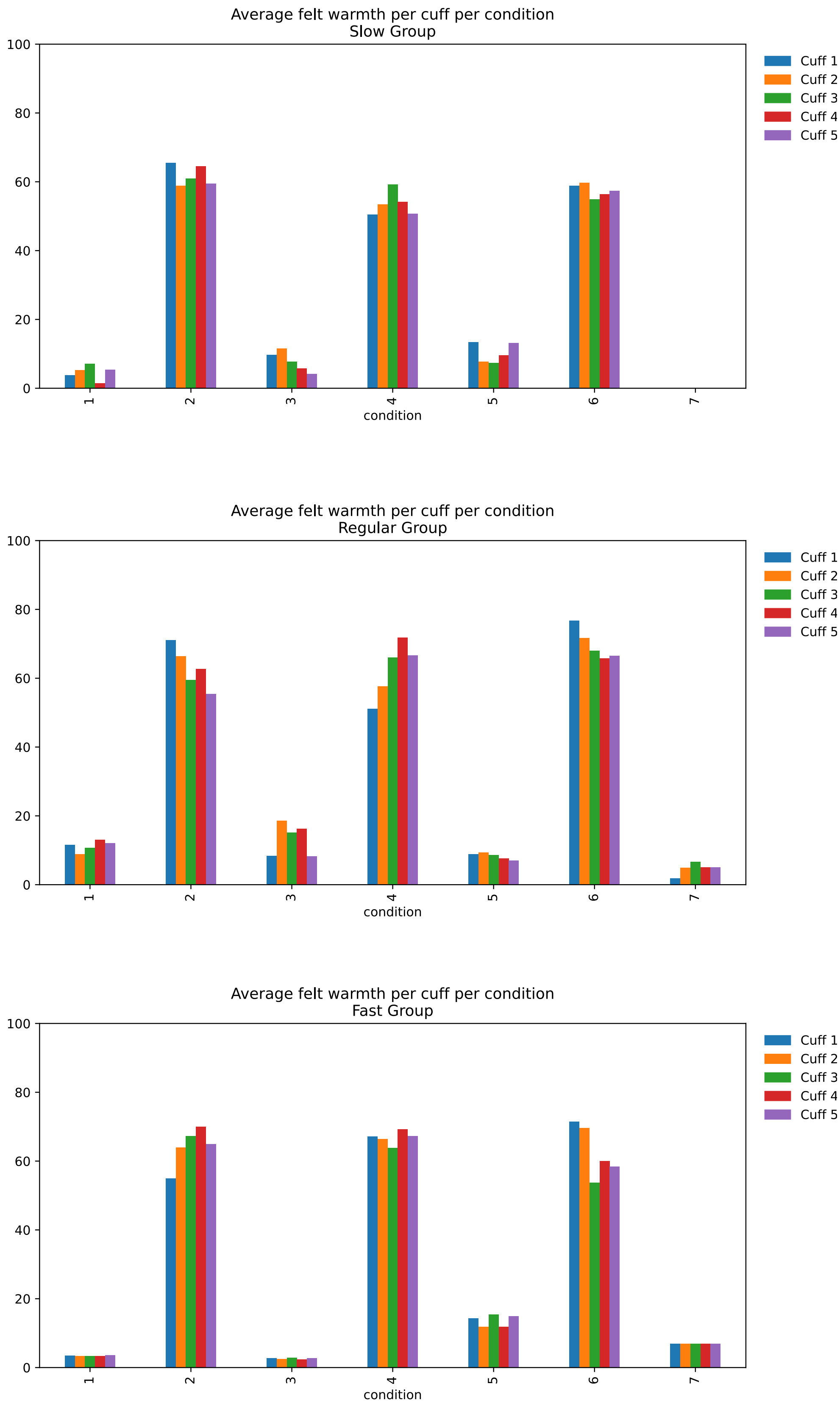


FIG II. 40
Average felt warmth per cuff per condition. Top: Slow group. Middle: Regular group. Bottom: Fast group.

When all the cuffs of the sleeve produce warmth and pressure at the same time, participants perceive the middle area of the sleeve (between the wrist and the elbow) as the area receiving greater warmth and pressure. When the cuffs produce warmth and pressure starting from the wrist and moving towards the elbow, it is the first cuff and last cuff that are perceived as providing the greater amount of warmth and pressure. Another interesting observation is that the values of pressure and warmth are usually in agreement (if the perception of pressure is high in a specific cuff, usually the perception of warmth is also high). The intensity of warmth typically follows the intensity of pressure, and is evaluated as a little less intense than the pressure in the same cuff. The evaluations for pressure and warmth are done in different questions and sliders, so the correlation can neither be accidental nor biased by the UI design [FIG II. 39-41].

In the UI survey, after each haptic condition, participants were also asked to rank the sensations of warmth and pressure regarding their degree of pleasantness. The participants used a slider with the markers “Very unpleasant; A bit unpleasant; Neutral; A bit pleasant; Very pleasant” but were prompted to place the slider knob anywhere -- on the markers or between them. The knob positions were returned as numeric values between 0 and 100. I plotted the results using the markers shown to the participants and grouped the evaluations per condition for each group. For each condition, I plotted both the mean values regarding pleasantness of pressure and the mean values regarding pleasantness of warmth, even though these were evaluated by participants in separate questions [FIG II. 42].

Comparing the results between the two sensations, one can see that evaluations between pressure and warmth sensation regarding pleasantness are usually in agreement, as the sensations are both rated more or less equally pleasant for each condition. Comparing the evaluations for each individual group, one does not observe many significant differences between the groups. Conditions are typically evaluated above neutral in terms of pleasantness regarding pressure and warmth. It is noticeable that conditions 3 and 5 are rated as more neutral in the Fast group when compared to the Slow and Regular groups. One should not be confused with the rating of warmth and pressure in the conditions that do not produce warmth or pressure (conditions 1,3,5,7); these are the mean values of the ratings given by the very small percentage of participants who felt a placebo or carry-over effect of warmth or pressure. It is nevertheless interesting that the placebo or carry-over effect of the sensations was evaluated as neutral or above neutral in terms of pleasantness.

Affective evaluation of the sleeve's haptic action. Bar graphs. For the affective evaluation of the sleeve, the survey included eight questions with sliders, each corresponding to the following affective states: Tense/Jittery; Placid/Calm; Upset/Distressed; Serene/Contented; Sad/ Gloomy; Elated/Happy. These affective states were chosen based on the Circumplex Model of Affect [reference]. The eight affective states make up the following four pairs of opposite states (negative and positive) of the same affective dimension: Tense/Jittery -- Placid/Calm; Upset/Distressed -- Serene/Contented; Sad/Gloomy -- Elated/Happy. I asked participants to evaluate each affective state separately (and not in pairs) to allow more nuanced responses and avoid any bias introduced by the adopted affective model. The sliders, each corresponding to the six mentioned affective states, had five markers corresponding to the following labels: "Not at all," "A little," "Moderately," "Quite a bit," and "Extremely." The participants could place the knob anywhere on or between the markers to allow for greater nuance in the responses. The responses were mapped onto a numeric scale from 0.0 to 100, with the values on the markers returning values of 0, 25, 50, 75, and 100 respectively.

The affective evaluation survey appeared eight times in the study, once at the beginning of the study and once at the end of each of the seven haptic conditions. The survey filled out before the testing of the haptic conditions was used as a pre-testing assessment — as a baseline affective state of the participants before experiencing the haptic conditions of the sleeve. To arrive at conclusions regarding the state of participants before testing, I calculated the mean values for each affective state for each of the three groups separately and for all the participants combined. To visualize the results, I created bar graphs showing the mean values for each affective state for each group in comparison, and a bar for each state corresponding to the mean values of all participants [FIG II 43a-b].

Comparing the mean values of the different groups for each affective state, one can observe that the prevalent state before testing is "Tired/ Lethargic": on average participants entered the study feeling a little more than "moderately" tired (56/100). The affective states that received the smaller values on average were "upset/distressed" (22/100) and "sad/ gloomy" (23/100). Participants on average entered the testing session in a moderately "placid/calm" (53/100) and "serene/contented" state (46/100); some entered "excited/enthusiastic" (37/100). None of the states received a very low or very high evaluation score when considering the averaged responses of all participants before testing. The pretesting survey took place after the short baseline phase and before the habituation and main testing phase [FIG II 43a — top].

When comparing the different groups in the evaluation of each affective state, we observe that the pretesting survey shows no great differences

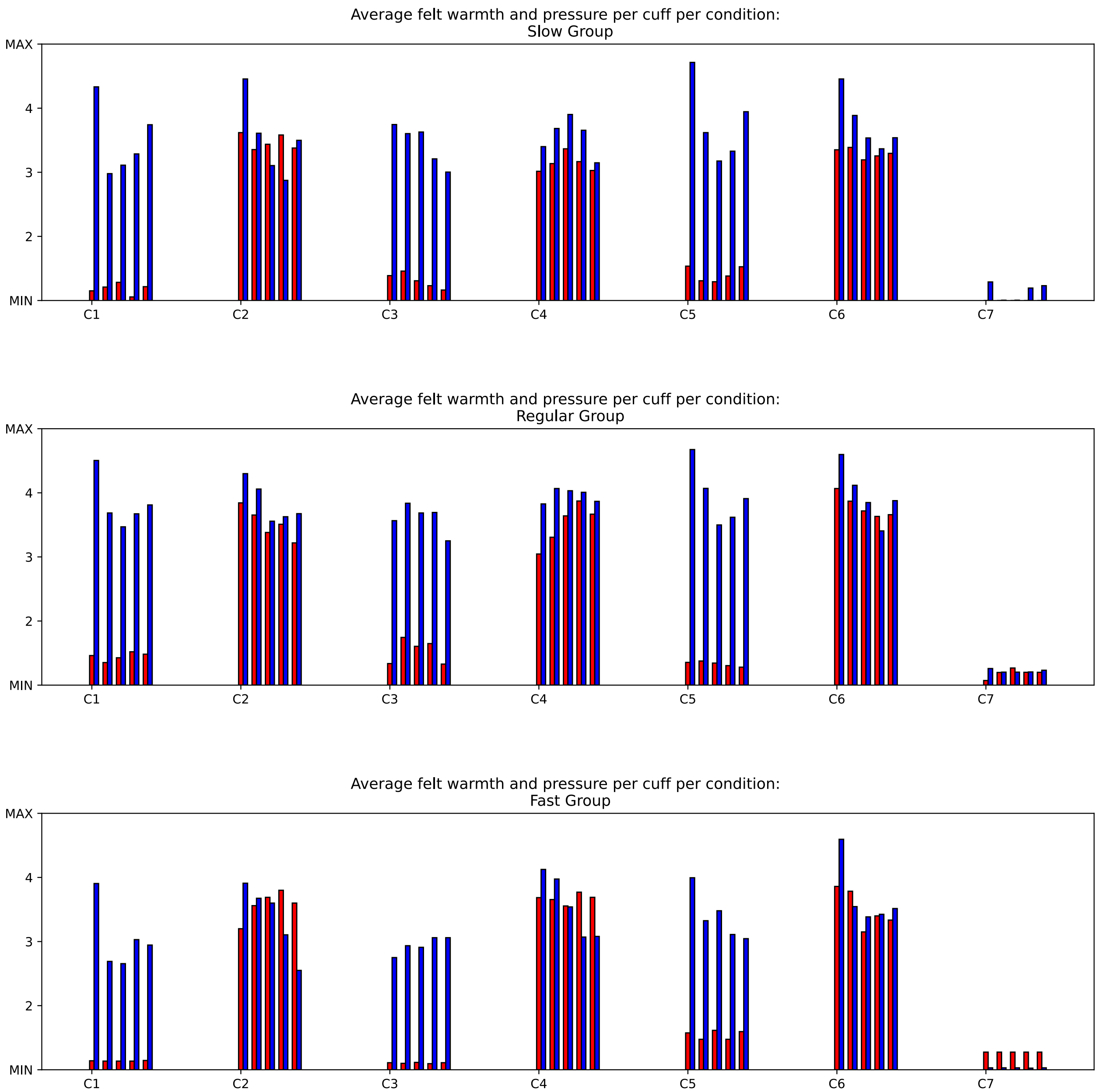


FIG II. 41
Average felt warmth (red) and pressure (blue) per cuff per condition. Top: Slow group. Middle: Regular group. Bottom: Fast group.

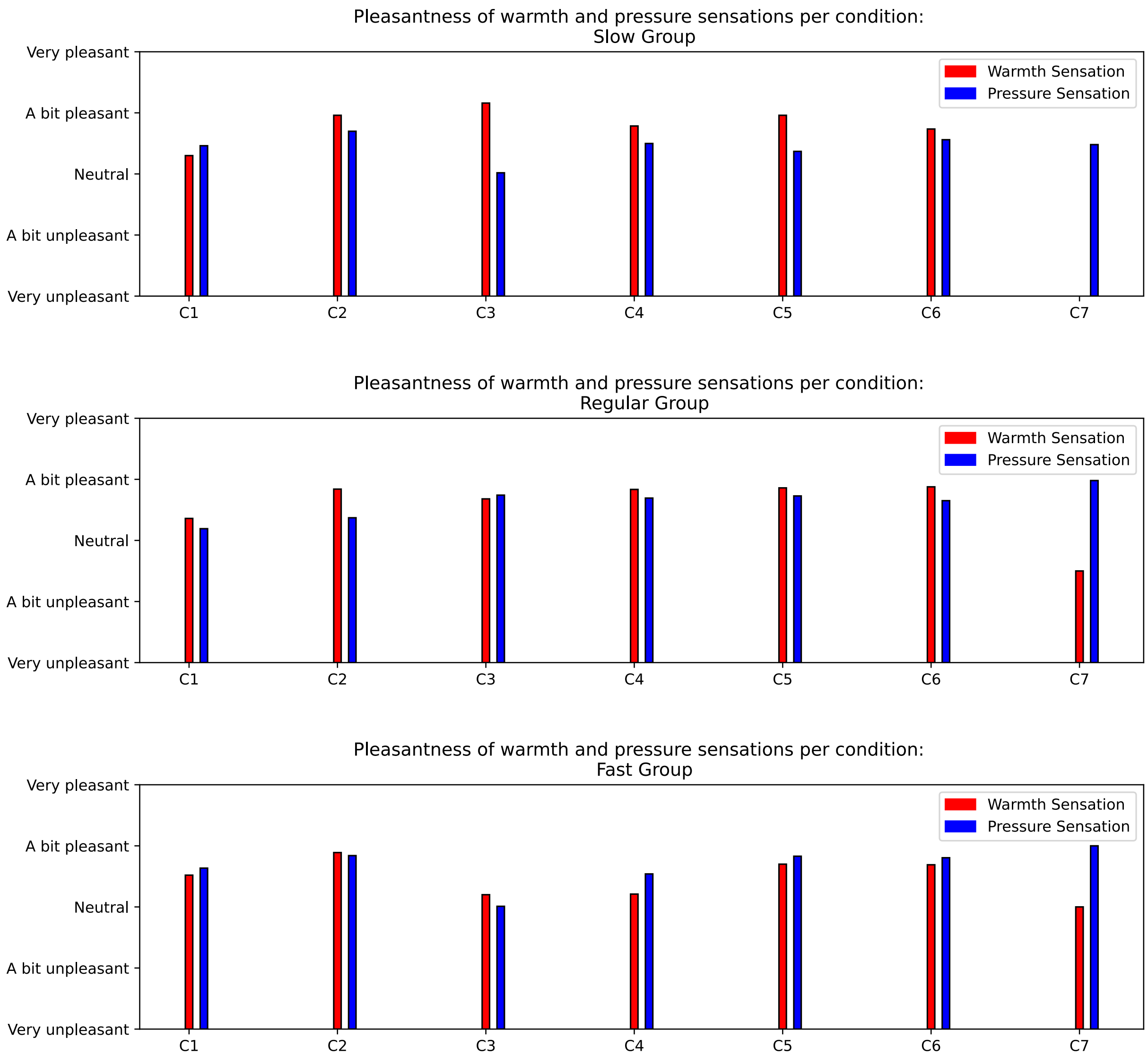


FIG II. 42
Pleasantness of warmth (red) and pressure (blue) sensations per condition. Top: Slow group. Middle: Regular group. Bottom: Fast group.

between them. On average, participants of the three groups entered the study sessions with only small differences regarding their overall mood. Participants of the Regular group were in a slightly more positive mood than those in the other two groups, as they gave a little higher values to the states of “placid/calm,” “serene/contented,” “elated/happy” and “excited/enthusiastic” than participants of the Slow and Fast groups. Participants of the Fast group were in a slightly more negative mood, as they gave slightly higher values to the states “tense/jittery,” “upset/distressed,” and “sad/gloomy.” [FIG II 43a — top].

When comparing the mean values of the evaluation of the affective states in each condition between the three groups, we do not observe any major differences or identifiable patterns [FIG II. 57a-b]. The comparison between the groups becomes more meaningful when we calculate the absolute change in the affective state evaluation from the baseline measurements (i.e the difference between the value in the survey after the haptic condition and the value in the pretesting survey). I created a series of graphs showing the absolute change values for the affective states for each condition per group (and per groups combined) to compare participants’ mood change [FIG II.44a-c].

In the graphs showing absolute change from pre-testing assessment [FIG II. 44a-c] we can observe that in condition 1, mean values for each group demonstrate a decrease from the pre-testing assessment for most affective states, with a major decrease in the states of “Tired/Letharigic” for the Fast group and “Excited/”Enthusiastic” for the Slow group. In condition 2 we observe a similar pattern, with a few more states demonstrating noticeable change from pre-testing assessment. Haptic conditions 1 and 2 are of the same pattern of haptic action (sequential activation of the cuffs) but only condition 2 includes warmth. This result is aligned with the analysis of EDA and BR data, where conditions including warmth typically show greater physiological impact. The state of “Serene/Contented” is interestingly the only affective state that demonstrates a minor increase in all groups.

In the graphs showing absolute change from pre-testing assessment [FIG II. 44a-c], in conditions 3 and 4 involving a pattern of simultaneous activation of the cuffs, with added warmth in condition 4, there is a noticeable increase in the mean values of the participants of the Slow group for the state of “serene/contented” and a decrease in most of the rest of the affective states for all groups. We observe an important decrease in the feeling of being “Tired/Lethargic” in the Fast group and the feeling of being “Excited/Enthusiastic” in the Slow group. Comparing the evaluations between conditions 5 and 6, which are of similar pattern (sequential activation in half cycle, with condition 6 having added heat) we observe a similarity in affective changes. Unlike the previous conditions, in conditions 5 and 6, we note an increase in the states of “Placid/Calm” and “Serene/Contented’’ for the Fast group. The states of “Tired/Lethargic” and “Excited/Enthusiastic” are significantly decreased from pre-testing evaluation for the Fast and Slow groups, respectively.

Overall, the graphs showing absolute change from pre-testing assessment [FIG II. 44a-c] primarily show consistency in the evaluation between conditions of the same pattern and a significant positive change in the feeling of “tired/lethargic” and “excited/enthusiastic’’ for the Fast and Slow groups, respectively. To investigate the differences of the affective evaluations for each condition, I utilized pairs of opposite affective states as defined by the Circumplex Model of Affect [reference] to draw conclusions for each affective dimension through the comparative analysis of the values for those opposite states. I created a series of graphs where “Tense/Jittery” and “Placid/Calm” represent the negative and positive spectrum, respectively, of the first affective dimension; “Upset/Distressed” and “Serene/contented” represent the negative and positive spectrum of the second affective dimension; “Sad/Gloomy” and “Elated/Happy” the negative and positive spectrum of the third affective dimension; and “Tired/Lethargic” the negative and positive spectrum of the fourth affective dimension.

When comparing all conditions per mood for each of the three groups separately [FIG II. 45a-d] we observe that the positive and negative evaluations in each of the affective dimensions are usually of approximately “complementary” values. For example, looking at the graphs of the Slow group [FIG II. 45b], we can see that the values for “Serene/Contented” are between 50 - 75 and the values on the other end of the dimension -- the state of “Upset/Distressed”-- are between 0 - 25. Such difference is consistent with the Circumplex Model of Affect; according to dimensional theories of emotions, one cannot be in an upset and a serene state at the same time. Although this is more or less true for most of the evaluations in the affective dimensions, it is interesting to observe that in the Regular group [FIG II. 45c] the evaluations in the affective dimensions tend to be more symmetrical, balancing each other out. For example, the evaluations in the dimension “Tense/Jittery - Placid/Calm” are for both the negative and positive side of the affective continuum between 25-50.

The symmetric shape in the graphs showing the evaluations for conditions per mood observed in the Regular group [FIG II. 45c] could mean that either there is a greater distribution of values than in the other two groups, with some participants on one end of the spectrum and some on the other, or it could mean that participants were in a more neutral or conflicted state. Looking at the error bars representing the standard deviation for each condition, we can see that the distribution of the values

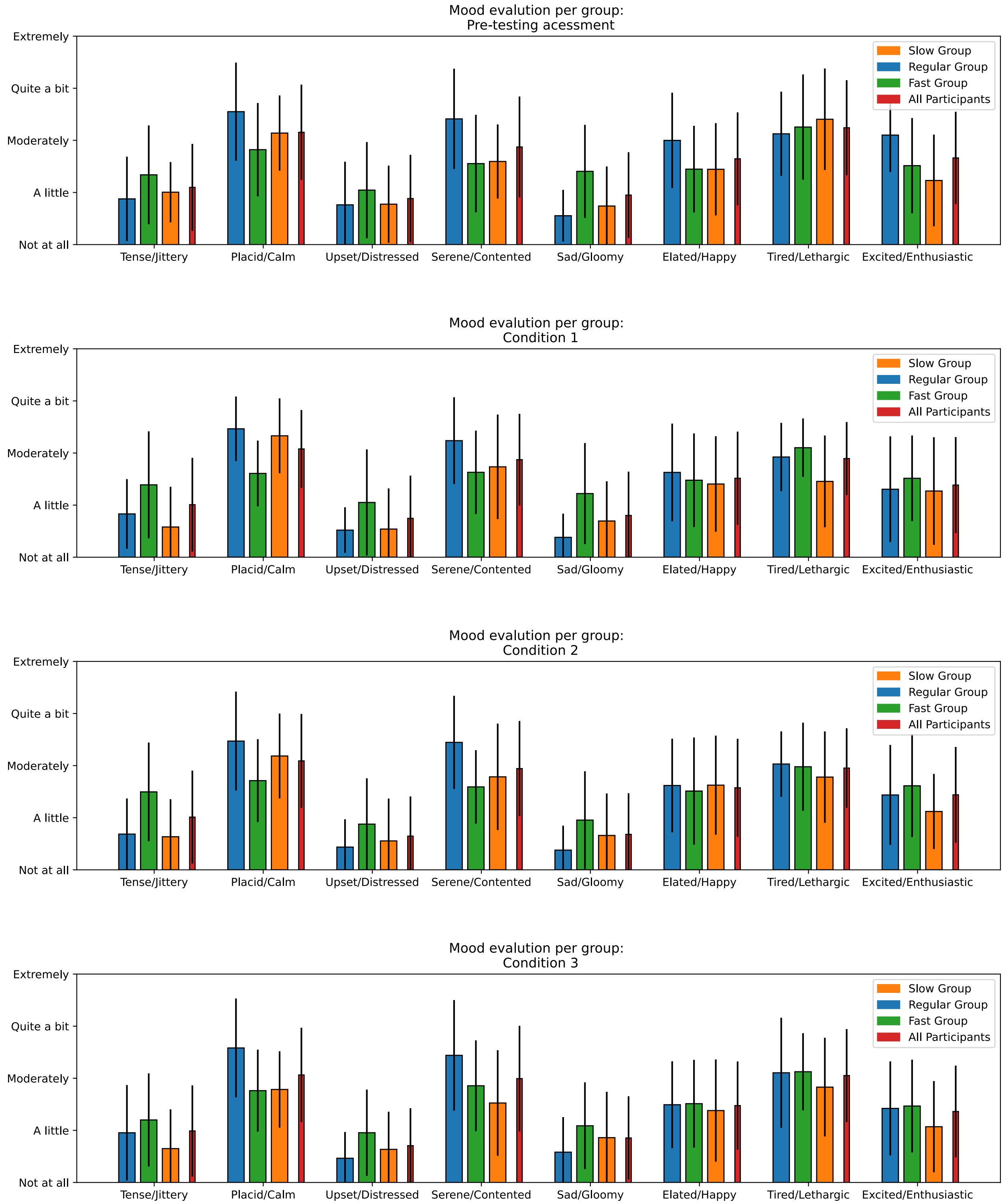


FIG II. 43a
Mood evaluation per group: Pre-testing assessment, Condition 1, Condition 2, Condition 3 (order from top to bottom).

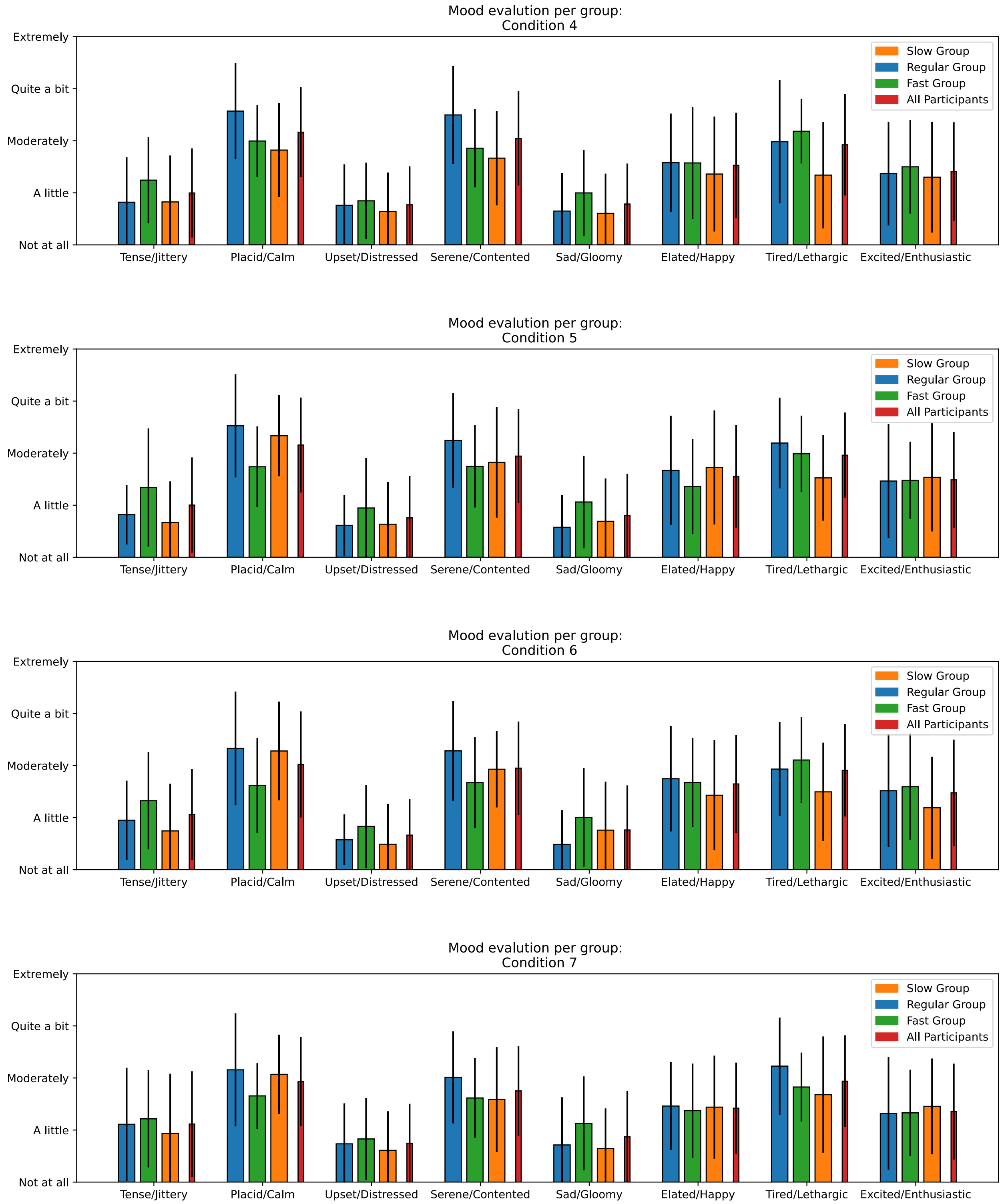


FIG II. 43b
Mood evaluation per group: Condition 4, Condition 5, Condition 6, Condition 7 (order from top to bottom).

in the Regular group is about the same compared to the Slow and Fast groups. To be exact, it is actually rather smaller than greater: the mean standard deviation of all conditions is 16.8 for the Slow group, 16.2 for the Regular group, and 17.0 for the Fast group [FIG II. 45b-d]. Thus we can assume that interestingly, participants in the Regular group felt moderately negatively and positively at the same time, a fact that could be interpreted as ambivalence or neutrality.

To obtain a different perspective on the results, I created a series of graphs showing the evaluation for the four affective dimensions for each condition per group, for all three groups [FIG II. 46a-c]. Analyzing the data in the Slow group, it is interesting to observe that participants begin by being equally tired and excited. In the pretesting survey, participants in the Slow group on average reported feeling moderately “Tired/Lethargic” and moderately “Excited/Enthusiastic” (53.1 and 52.5 respectively). In the Slow group, it is interesting to observe that while the levels of tiredness remain about the same in all conditions, the levels of excitement drop noticeably during the study.

When compared to the Slow and Regular group, the Regular group again shows more symmetry between the opposite affective states in the various affective dimensions; we notice that the affective dimensions in the haptic conditions in the Regular group have more similar values on their positive and negative spectrum than do the affective dimensions in the Slow and Fast groups. In the graphs of the Regular group, we notice again that participants start off almost equally tired and excited, but unlike the Slow group this symmetry is retained in most of the conditions. Interestingly, in the Fast group, participants also start off noticeably more “tired/lethargic” than “excited/enthusiastic,” but the tiredness drops and the excitement increases during the study.

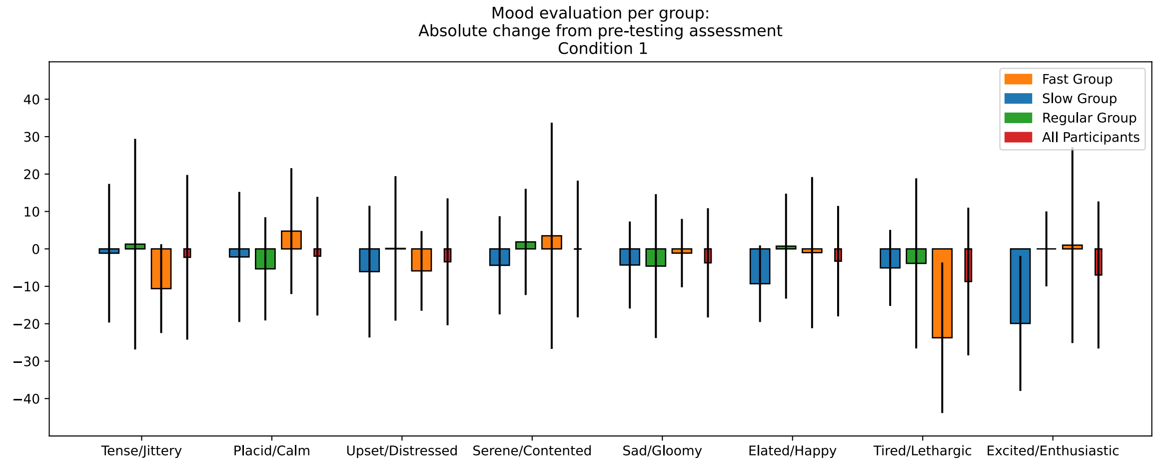
The observed symmetry in the affective dimension exposes the limits of the dimensional approach in regard to emotion evaluation, as it demonstrates a more nuanced response than expected by the Affective Circumplex Model: sometimes one can have opposite or conflicting affective states at the same time. The limitations of dimensional models such as the one proposed by Russell [1980] have been previously discussed [Norman et al., 2011; Picard et al., 2016]. For example, although one of the first dimensional models proposed by Wundt [1987] included an “arousal,” a “valence” and an “intensity” dimension, modern two dimensional approaches often regard an intense state as being identical to a high arousal state, which is not always the case, as in the state of depression. [see Picard et al., 2016, for a discussion].

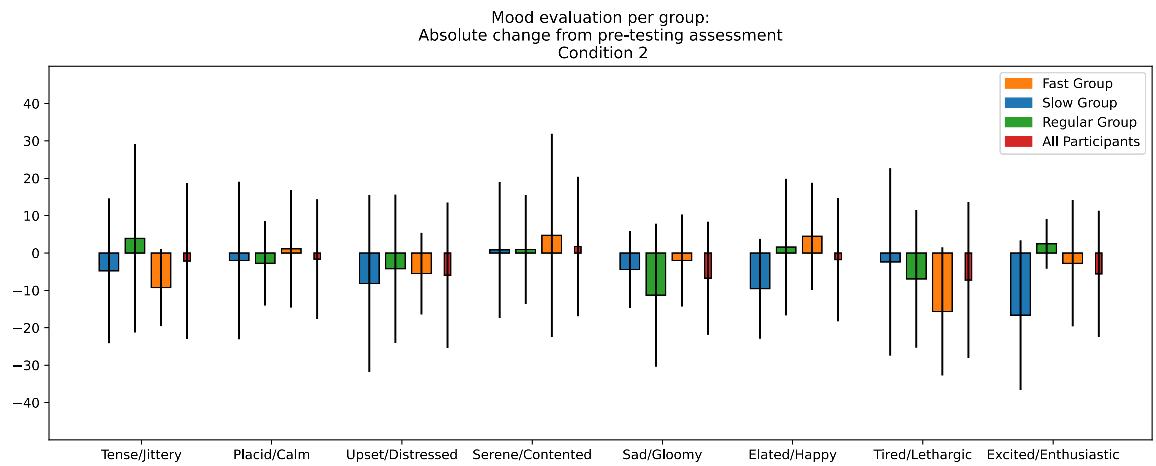
In the same work, Picard et al, also expose the limitations of the assumed symmetry between measurements of electrodermal activity signals of one's left and right side, demonstrating individual cases of physiological asymmetry. Both the asymmetry in the arousal observed by Picard et al. [2016], and the "conflicting" affective states that I observed in my study, are in support of the same neuroscientific approach to emotions that regards affective states as results of distinct and at least partially independent processes happening in multiple levels of the nervous system [Picard et al., 2016; Norman et al., 2011].

According to Norman et al.[2011], the ambivalent character of affective measurements and evaluations is reflected by the fact that organisms often have conflicting dispositions. For example, an organism might be scared of a potential threat while being highly motivated to put themselves at risk in order to approach a certain reward, such as drinking water. These evaluative conflicts are the basis of neurobiological and psychological processes that cannot be reduced to bipolar affective models. For this reason, Norman et al. [2011] support a bivariate representation of affective evaluation where negative and positive evaluations constitute district dimensions, as proposed by Cacioppo and Berntson [1994], rather than the opposite spectrums of the same continuum.

Taking advantage of the limitations of the bipolar structure of the Affective Circumplex Model, I created another series of graphs where I subtracted the opposite affective states for each affective dimension [FIG II. 47a-c]. In this series of graphs, some of the differences spotted in the earlier graphs become clearer. In the Regular group, we see clearly the increase of the "Tired/Lethargic" state from the pretesting survey, and in the Slow group we see clearly the decrease of the "Tired/Lethargic" state from the pretesting survey. We also see more clearly the results of the relative ambivalence or neutrality in the Regular group compared to the Slow and Fast groups: when opposite affective states of each affective dimension are subtracted, the remaining values are much smaller compared to the values in the Slow and Fast groups. We also notice that in all three groups, all values of difference are on the positive spectrum of the affective dimensions except for the dimension of "Tired/Lethargic - Excited/Enthusiastic," where in most conditions, the values are on the negative side.

The reviewed graphs reveal so far that when we consider the opposite affective states combined, the participants in the Regular group have a more neutral mood during the study than the participants in the Slow and Fast groups. We also notice that the differences within each group are usually small, as typically the same pattern of affective evaluation is maintained throughout the study. However, we do observe more significant changes in regard to the "Tired/Lethargic" - "Excited/Enthusiastic" dimensions when comparing the conditions within each





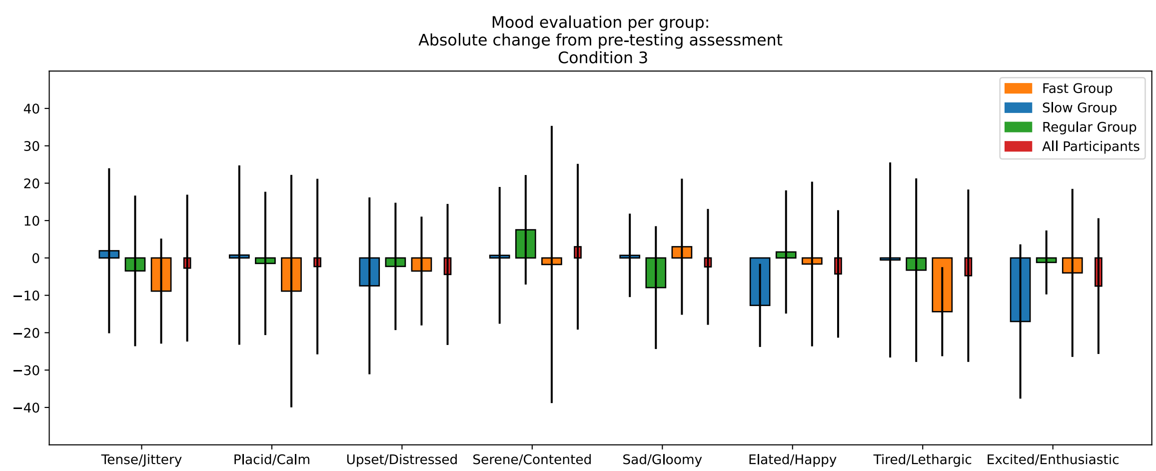


FIG II. 44a
Mood evaluation per group: Absolute Change from pre-testing assessment: Condition 1 - Condition 3

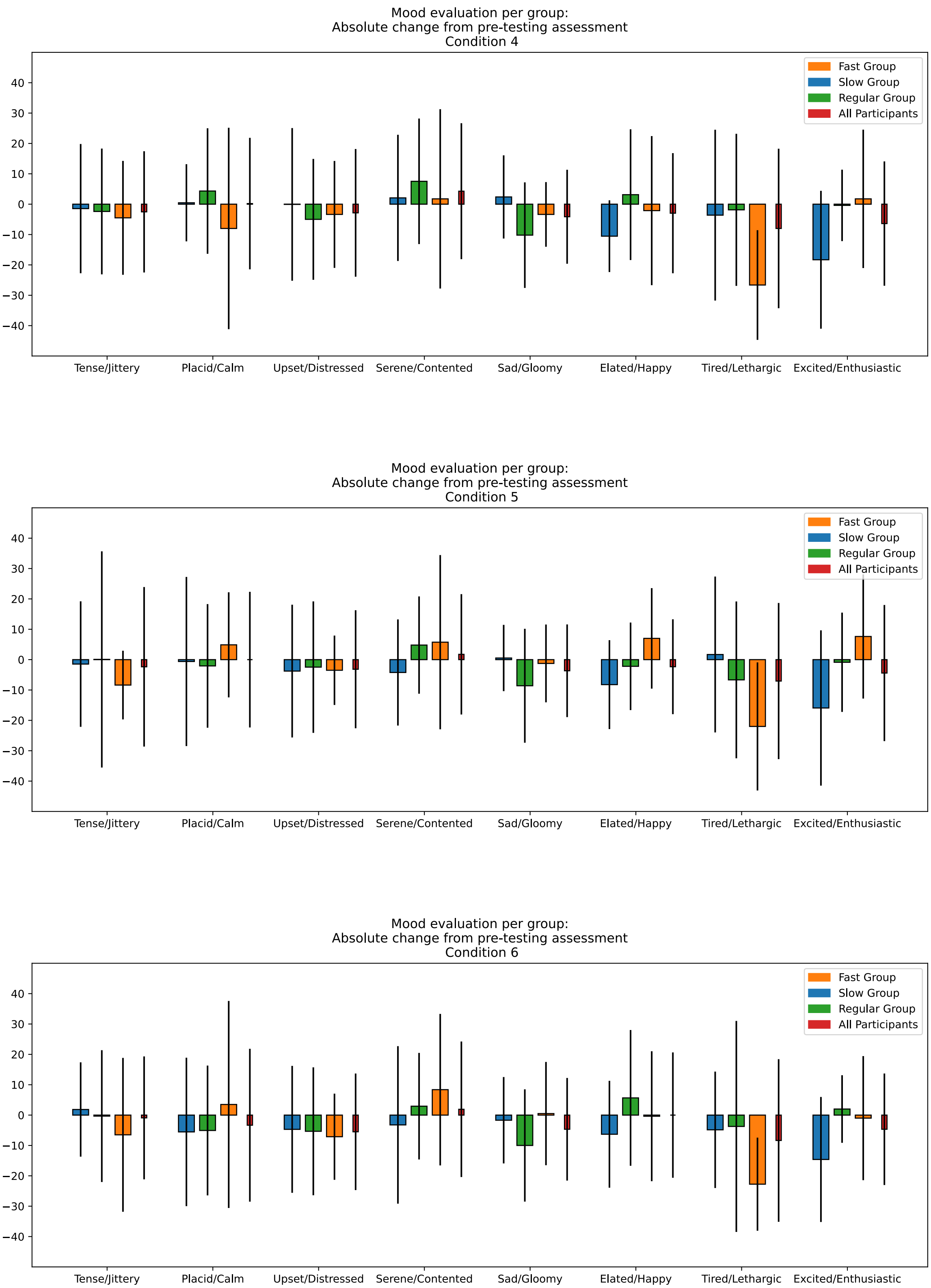


FIG II. 44b
Mood evaluation per group: Absolute Change from pre-testing assessment: Condition 4 - Condition 6

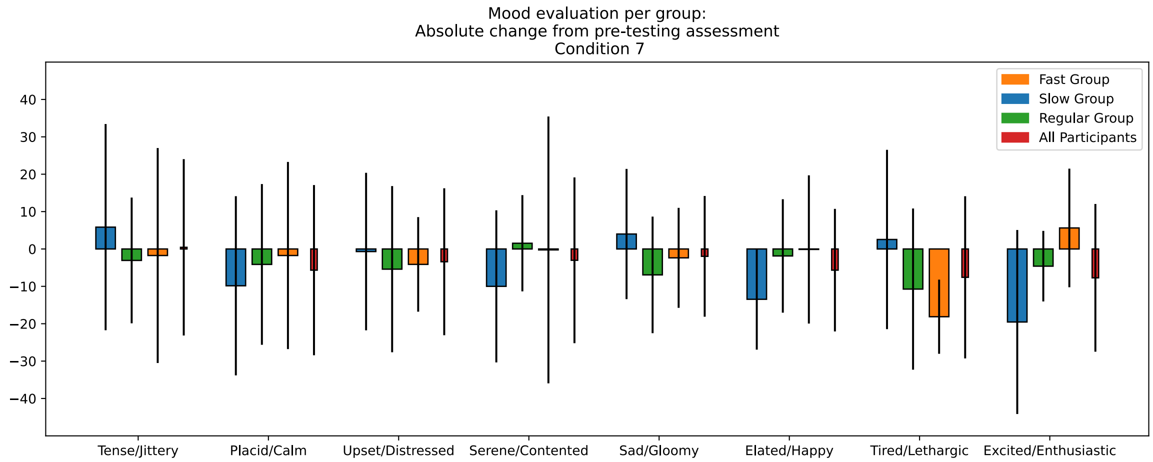


FIG II. 44c
Mood evaluation per group: Absolute Change from pre-testing assessment: Condition 7.

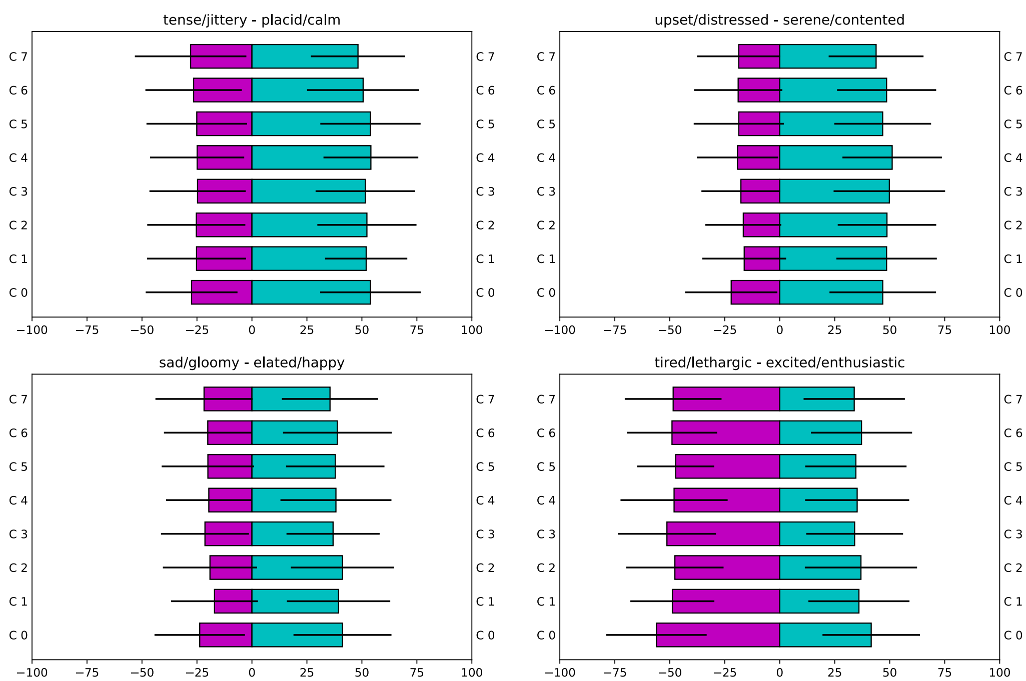


FIG II. 45a
Mood evaluation (all conditions per mood): All participants.

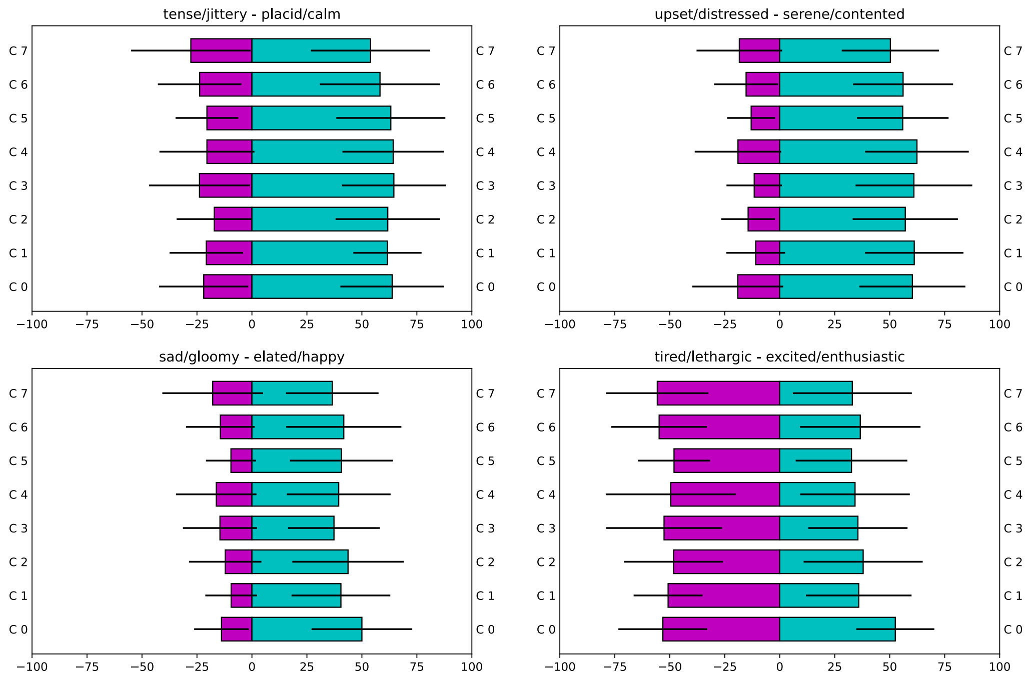


FIG II. 45b
Mood evaluation (all conditions per mood): Slow group

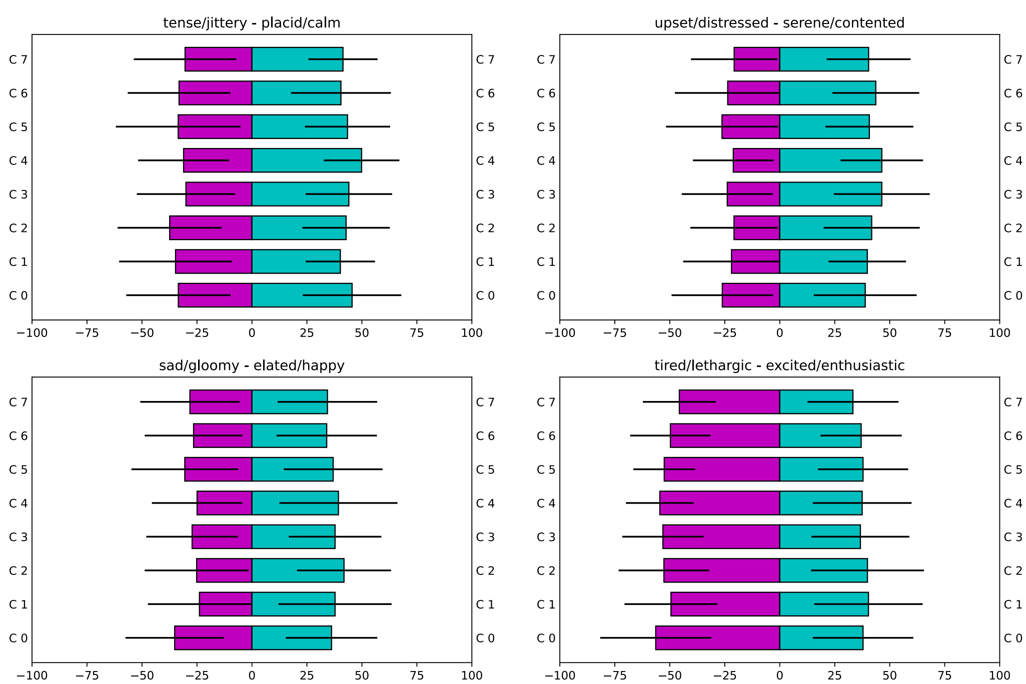


FIG II. 45c
Mood evaluation (all conditions per mood): Regular group

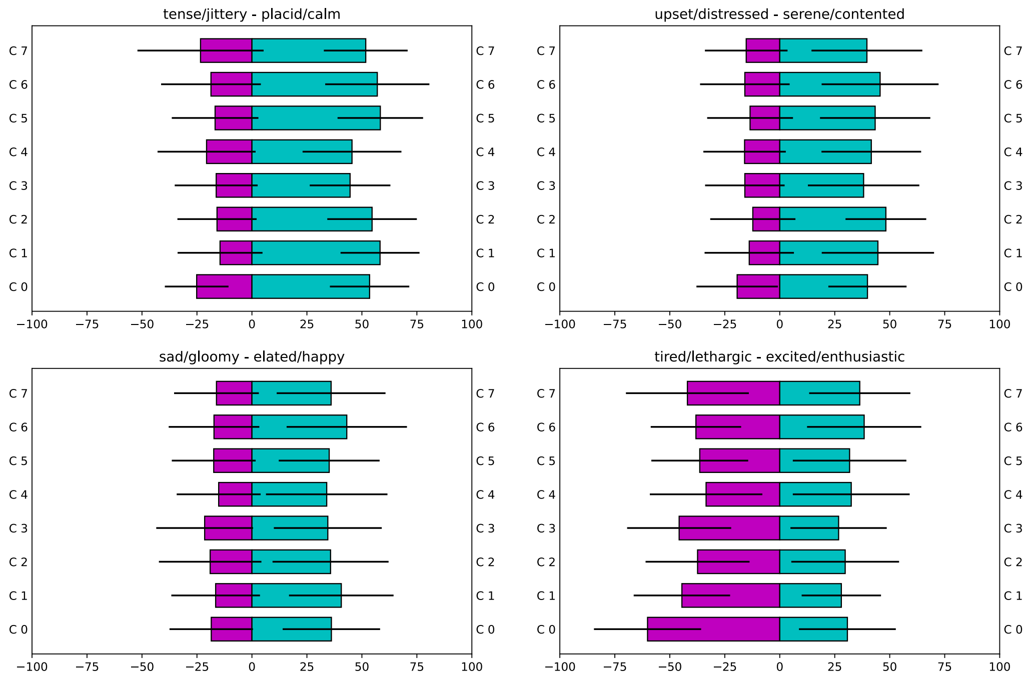


FIG II. 45d
Mood evaluation (all conditions per mood): Fast group

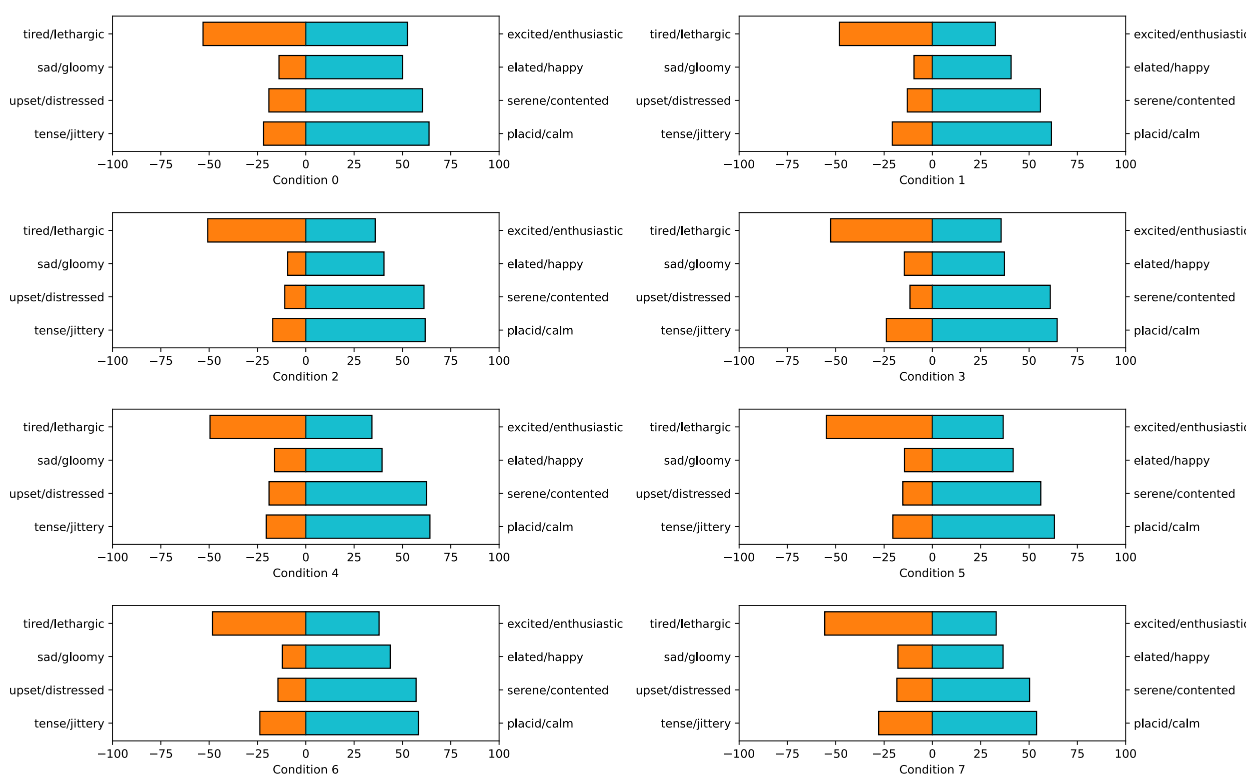


FIG II. 46a
Mood evaluation per condition (mean values): Slow group

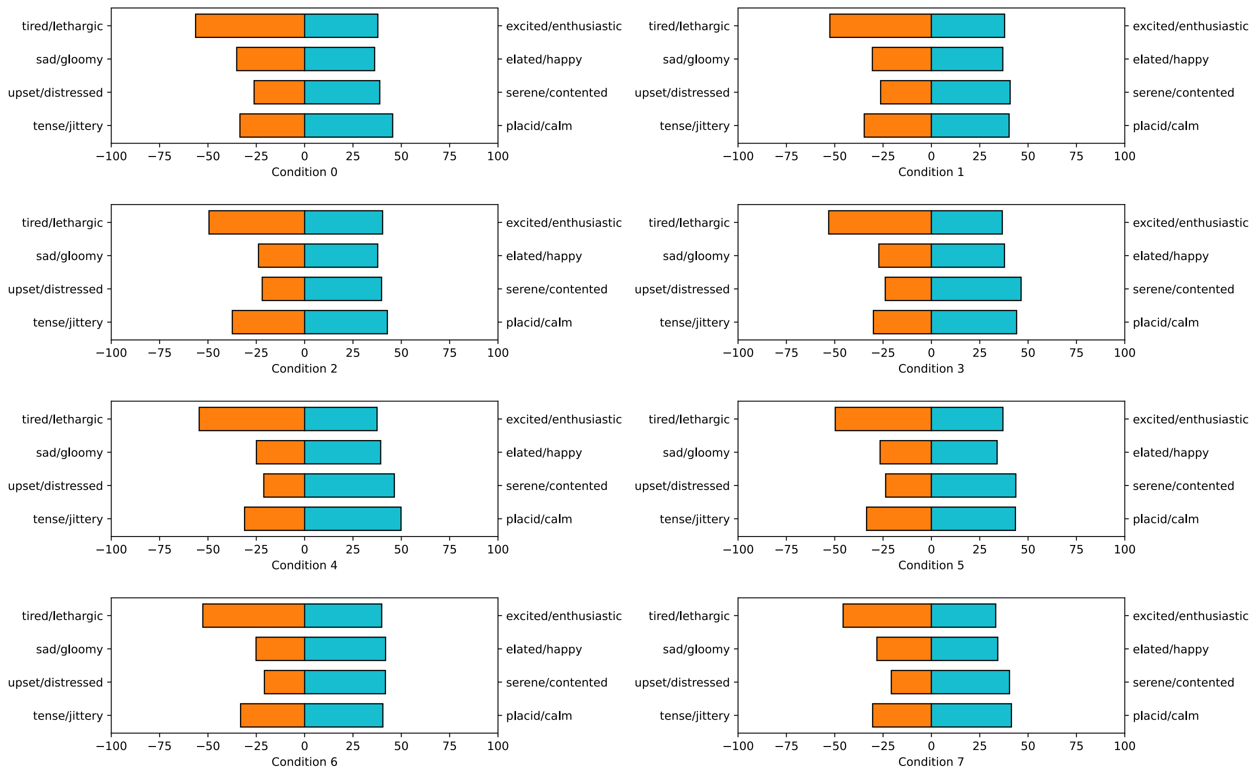
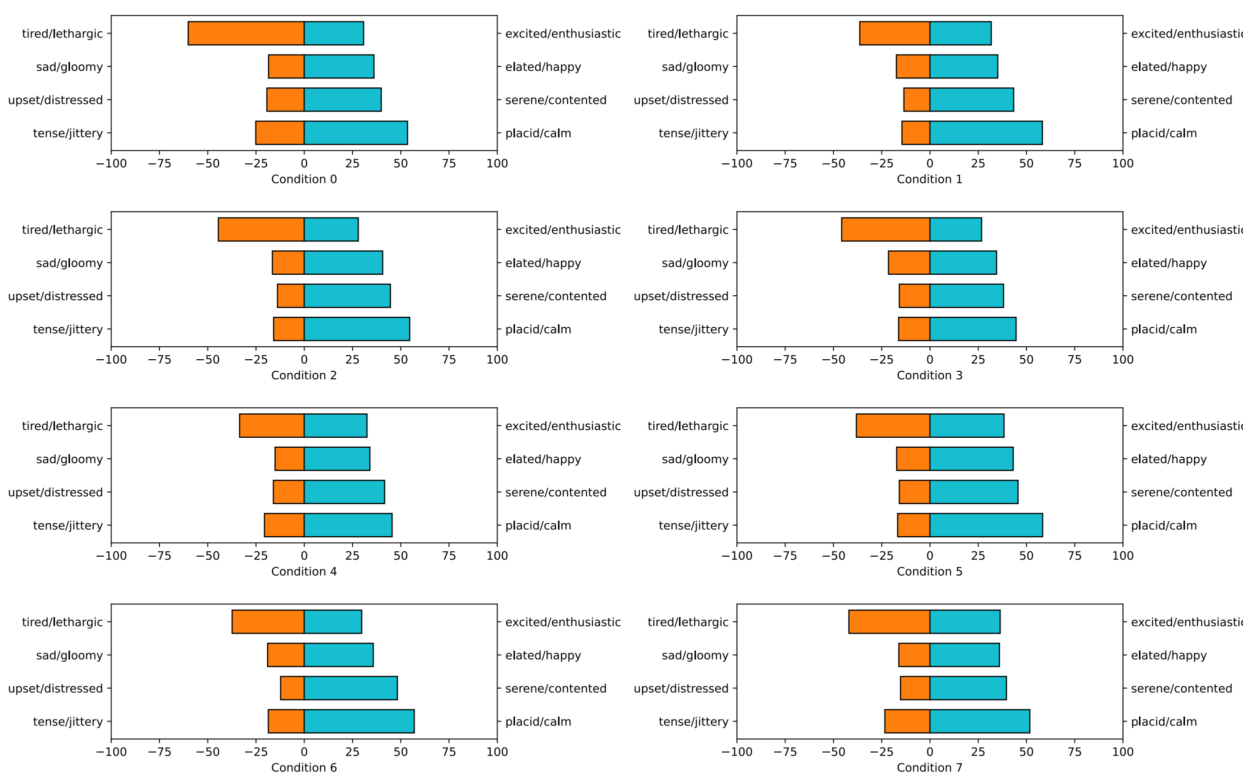


FIG II. 46b-c
Mood evaluation per condition (mean values): 46 b (top): Regular group; 46 c (bottom): Fast group



group. When looking at the three groups together, we confirm the previously mentioned differences but do not observe others [FIG II. 47a-c].

The affective patterns of the three groups become very clear in the next series of graphs, where not only the opposition between the moods is taken into account but also the absolute change from the pretesting condition [FIG II. 48a-c]. For these graphs I first calculated the difference between the positive and negative affective states for each affective dimension in each condition and for the pretesting survey; I then calculated the absolute change in the value resulting from the subtraction of the opposite affective states from the respective value of the pretesting survey. The values of absolute change derive from the following formula, where A and B are the opposite affective states of an affective dimension, and C is a particular haptic condition:

Change = (value of positive affective state A in haptic condition X during testing - value of negative affective state B in haptic condition X during testing) - (value of positive affective state A in haptic condition in pretesting - value of negative affective state B in haptic condition in pretesting)

In the graphs of absolute change from pretesting with subtraction of opposite moods per group [FIG II. 48a-c], it is exciting to observe significant differences between the three groups: On average, the participants in the Slow group demonstrate an increase of negative affect, as most of the values in the affective dimensions are on the negative spectrum (with an approximate range of 5-20 on a 0-100 scale). Participants feel a bit sad and tired throughout the study (with a range approximately from 5 to 20 on 0 - 100 scale) but also feel somewhat serene and calm (with a range approximately from 5 to 10 on 0 - 100 scale) -- interestingly, the exception is condition 7, the control condition. Unlike the Slow group, in the Regular group we can see all values in the positive spectrum of the affective dimensions with the exception of the “Tense/Jittery” affective state ,which makes its appearance in 3 conditions, including condition 7.

In the graphs of absolute change from pretesting with subtraction of opposite moods per group [FiG II. 48a-c], we also notice that in the Fast group most values are on the positive spectrum of the affective dimensions with the exception of three values in three conditions: “Sad/Gloomy” in condition 3 (less than 10/100); “Tense/Jittery” in condition 4 (approx. 5/100); “Sad/Gloomy” in condition 6 (less than 5/100). Interestingly, compared to the Regular group, the positive values in the Fast group, which are on average between 10 to 30, are higher, with a significant difference in the “Excited/Enthusiastic” affective state, which is on average much higher than the Regular group.

At first, one might be surprised that the values in the Slow group fall in the negative values of the continuum of the bipolar affective dimensions. According to my hypothesis, aren't the participants in the Slow group supposed to be in a more relaxed and better mood than the participants in the Fast group? The answer is yes and no. Participants are supposed to be more "relaxed," but this does not mean they are necessarily in a "better" mood than others. What the results demonstrate is that participants in the Slow group are in lower arousal state compared to the participants of the Fast group. When individuals are in a low arousal state, they are more likely to feel tired and sad than when they are in a high arousal state. In contrast, when they are in a high arousal state, they are more likely to feel anxious but are also more likely to feel excited and energetic.

According to the Circumplex Model of Affect, all affective states fall at specific points in a two-dimensional space structured by two main axes: the High Arousal - Low Arousal axis with North - South orientation, and the Positive Valence - Negative Valence axis with West - East orientation. When the various affective states are distributed in the Circumplex, we observe that the state of being calm and the state of being tired are both located at the bottom semicircle of the Circumplex: calmness is a low arousal and positive valence state, while tiredness is a low arousal but negative valence state. Similarly, the state of feeling serene and the state of feeling sad are both on the negative side of the Arousal continuum and symmetrically located in regard to the Arousal axis. In contrast, the state of being tense and the state of being excited are on the positive side of the Arousal continuum, in neighboring sectors but with opposite valence. The state of feeling happy is also on the positive side of the Arousal axis, as is the feeling of being upset, and has opposite values in the valence axis.

Given the affective space defined by the bipolar affective dimensions of the Circumplex, and the results of the bar graphs regarding the evaluation of affective states, we can conclude that during the study, participants in the Slow group exhibited states of lower arousal than the participants in the Regular and Fast groups, and that participants of the Fast group exhibited states of higher arousal than participants in the Regular and Fast group. The bar graphs of absolute change in the affective states of participants with subtraction of opposite moods, demonstrate, on average, an increase in the negative values of the bipolar affective dimensions for the Slow group, and an increase of the positive values for the Regular and Fast groups, with the increase being higher in the Fast group than in the Regular group.

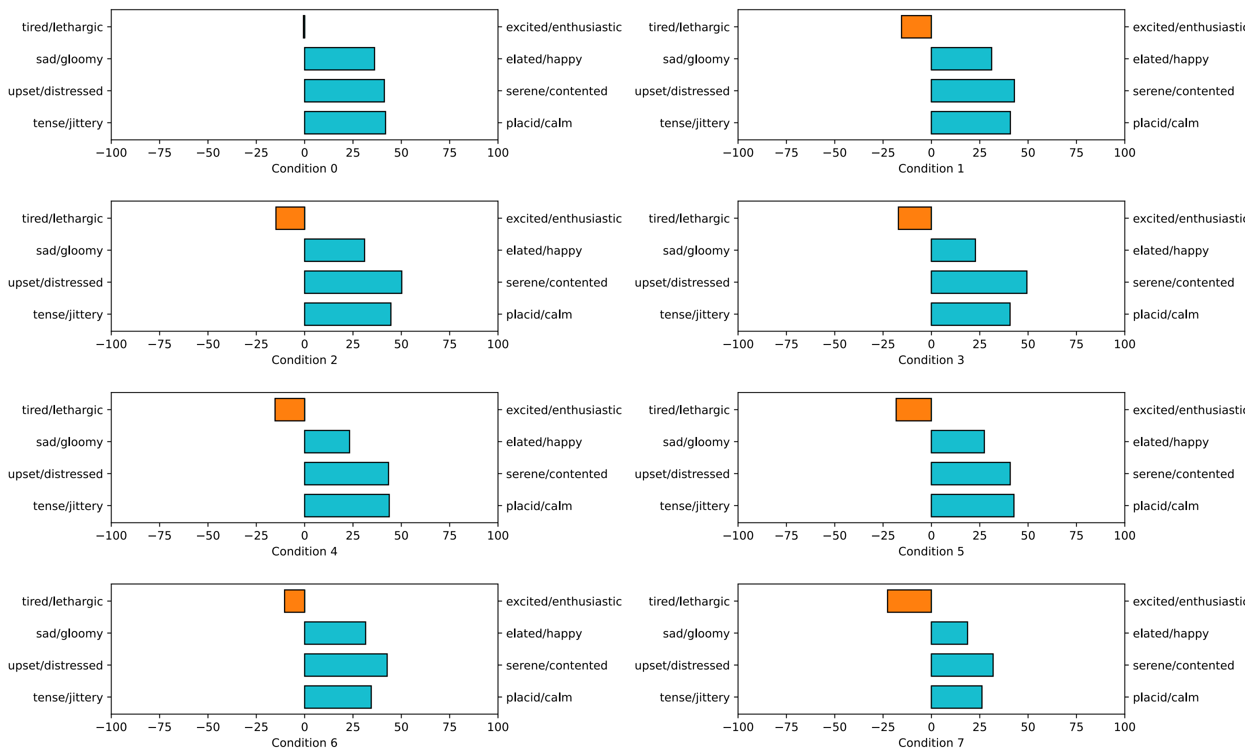
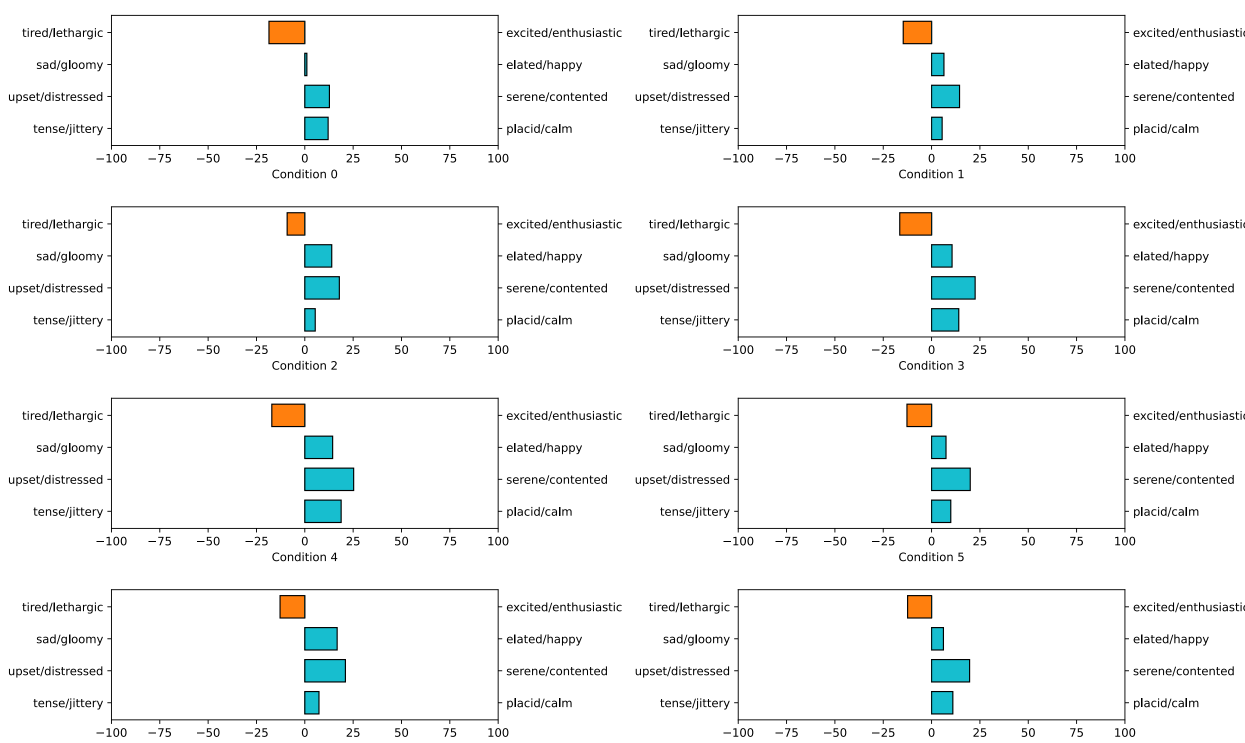


FIG II. 47a-b
Mood evaluation per condition. Subtraction of opposite moods: 46 b (top): Regular group; 46 c (bottom): Fast group



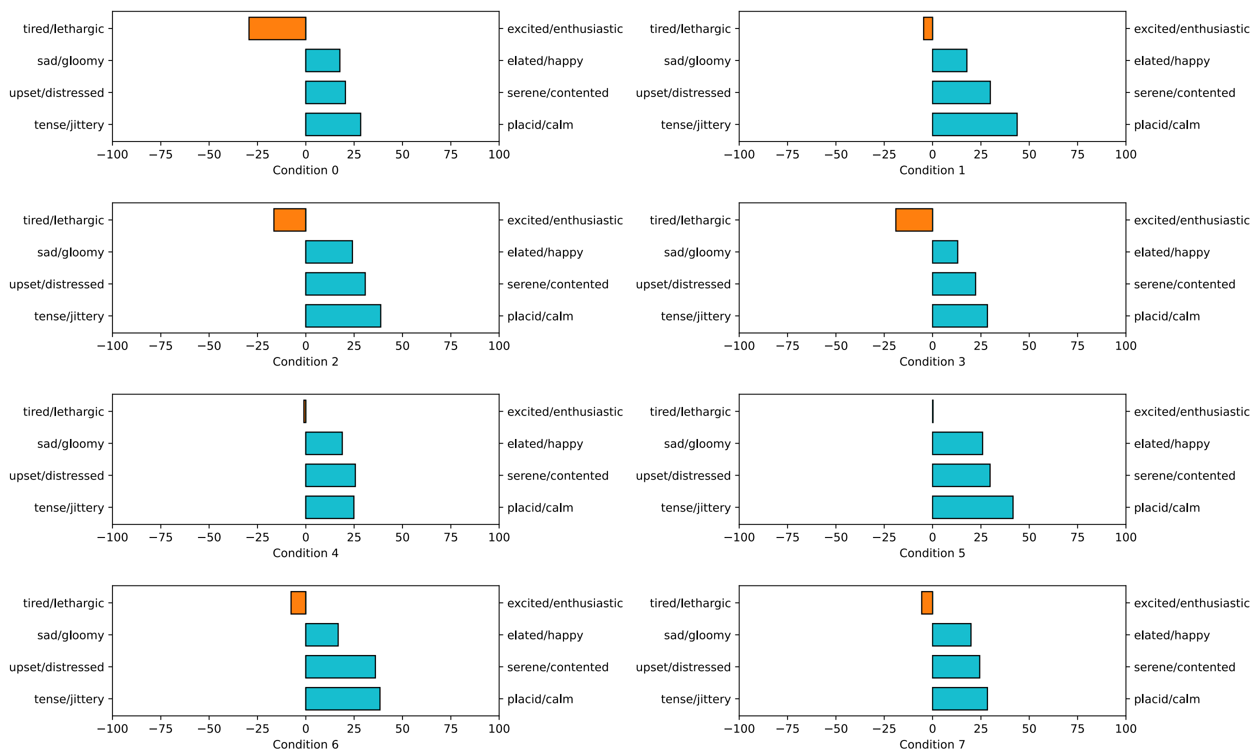


FIG II. 47c
Mood evaluation per condition. Subtraction of opposite moods: Fast group

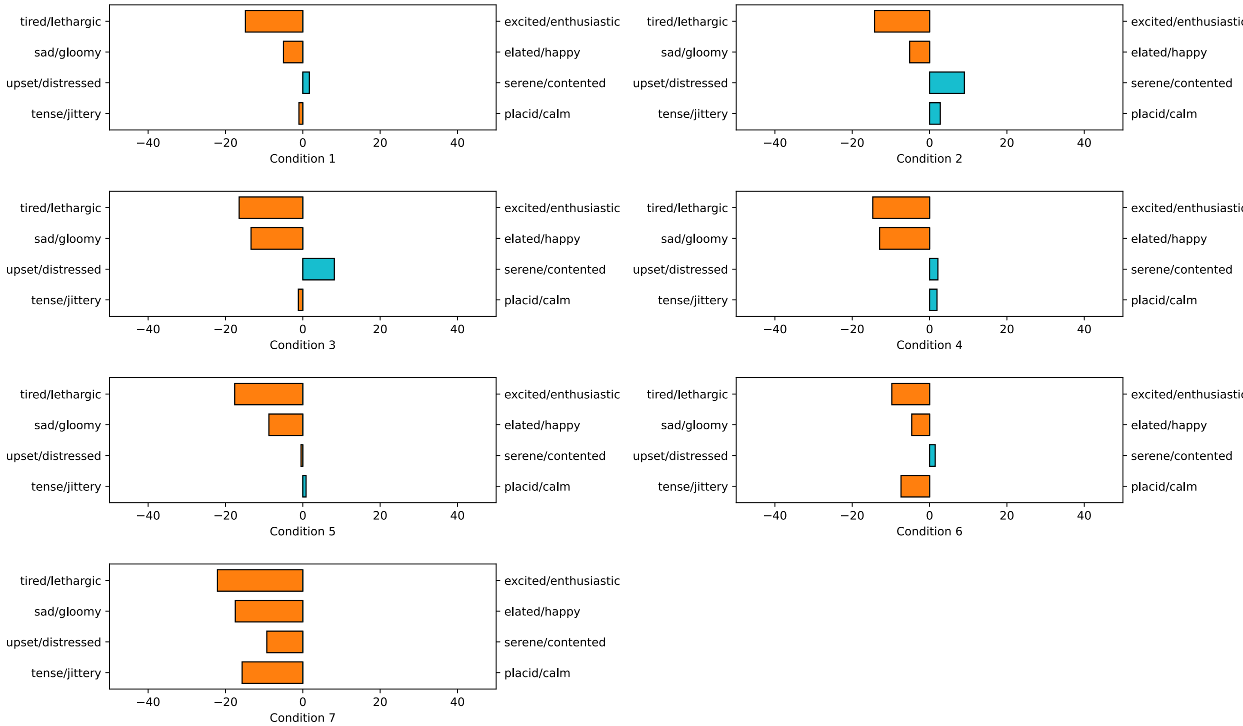


FIG II. 48a
Mood evaluation per condition. Absolute change from pre-testing with subtraction of opposite moods: Slow Group

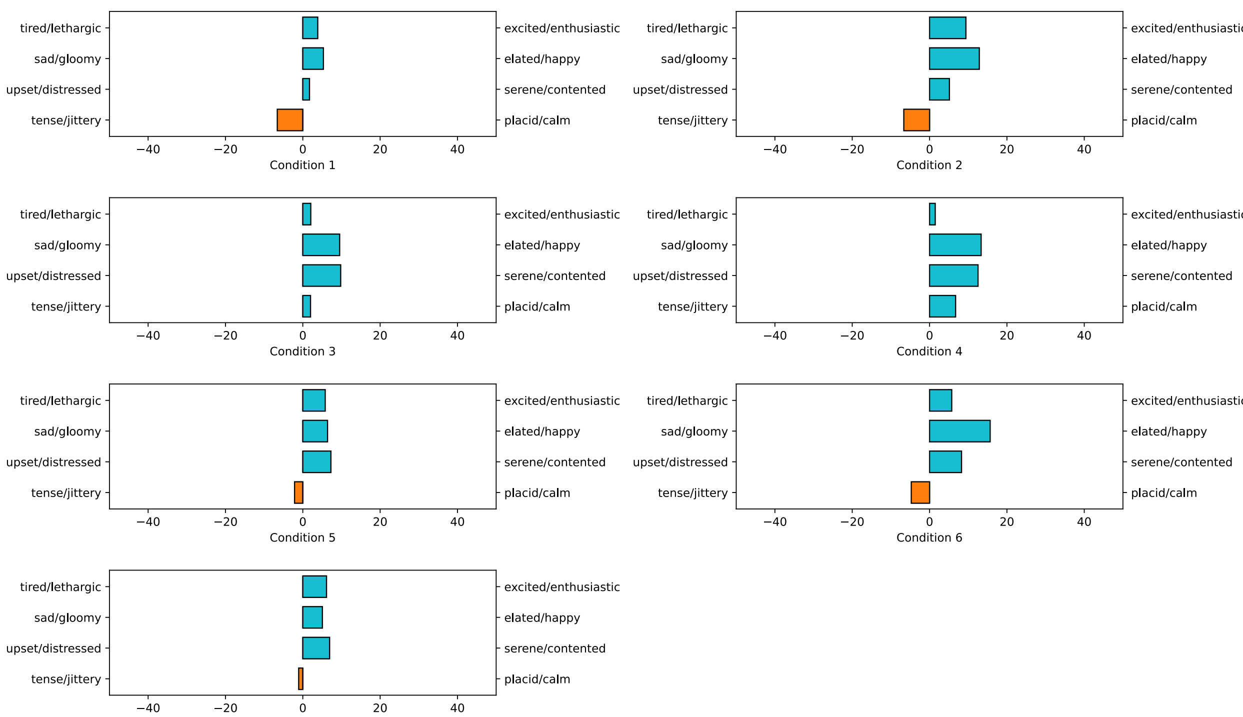


FIG II. 48b
Mood evaluation per condition. Absolute change from pre-testing with subtraction of opposite moods: Regular Group

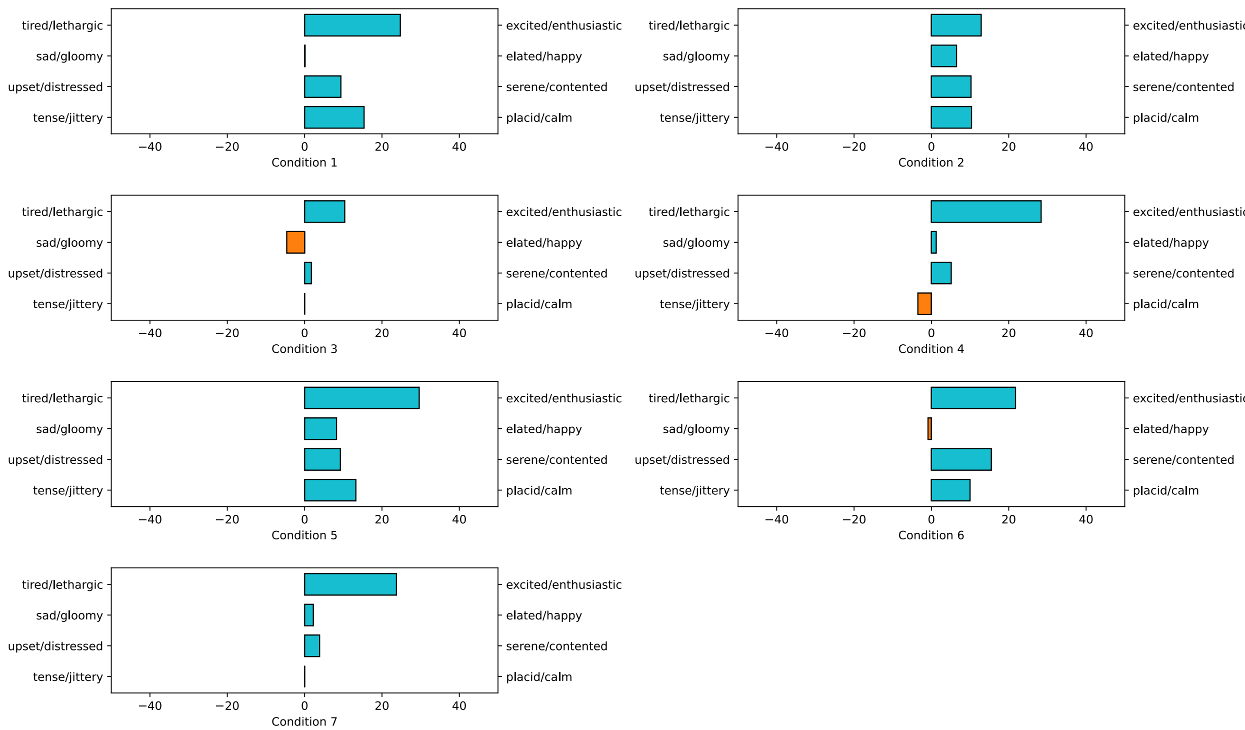


FIG II. 48c
Mood evaluation per condition. Absolute change from pre-testing with subtraction of opposite moods: Fast Group

Affective evaluation of the sleeve's haptic action. Radar charts. I created a series of radar charts that depict a two-dimensional affective space that emerges when the values of all the affective states are depicted in the graph [FIG II. 49a-c; 50]. It is important to note that my approach deviates from the one proposed by Russell in that it depicts a participant's affect for any given moment as a two-dimensional affective space rather than as a zero-dimensional point. According to Russell, at any given moment, one's affect (what Russell defines as "core affect") can be represented as a point in the Circumplex whose coordinates are defined by its values in the Arousal and Valence axes. My approach leads to a two-dimensional affective space because it is the reverse of the evaluation typically adopted in dimensional theories: instead of asking participants to mark the degrees of arousal and valence in a given continuum [Russell et al., 1989] participants are asked to evaluate various affective states of bipolar dimensions of the Affective Circumplex. Each evaluation can then be mapped back onto the Circumplex as it corresponds to coordinates of Arousal and Valence axes.

By allowing participants to rate all of the affective states that comprise the affective dimensions of the Circumplex, we receive a more nuanced representation of their affective space than we do with a point, which integrates affective ambiguities. Participants' affective space for each haptic condition is represented as an octagonal planar shape formed by the eight values of the four bipolar axes. To compare the results between the three groups, I created three series of radar charts, each consisting of eight charts, representing the seven haptic conditions and the pretesting survey (condition 0). The values of each individual participant are overlaid as a palimpsest of individual affective spaces that compose the collective affective space for each haptic condition of all participants in each group [FIG II. 49a-c]. When the mean values for each of the groups are calculated and overlaid on each of the charts representing each condition, we can see the comparison of the collective affective spaces occupied by each group [FIG II. 50].

The charts showing all individual values per participant per group [FIG II. 49a-c] are more revealing of the trends between the different groups than the charts with the overlay of the mean values of the groups as the latter smooth out individual differences [FIG II. 50]. Comparing the affective spaces for each condition in the three groups, we can again observe what was previously observed in the bar charts but in a more visually prominent manner. The affective spaces (as the overlay of the individual responses depicted as octagonal planar affective spaces) in the Slow group tend to gravitate towards the bottom right quadrant of the Circumplex. The affective spaces in the Regular group tend to gravitate towards the center of the Circumplex, being more symmetrical in regard to the bipolar dimensions when compared to the Regular and Slow groups. The affective spaces in the Fast group tend to gravitate towards the right semicircle of the Circumplex.

Interviews and Survey feedback. Scope and Methods. As part of the UI survey, after each of the haptic conditions, participants were asked to provide their input regarding the haptic condition they experienced. The following instructions were given: "Please provide any thoughts, comments or observations regarding the experience of haptic sensations of the sleeve you had during this session; Optionally compare with the experience of haptic sensations you had in previous sessions, if any." The input from this part of the survey was collected in a json file correlated to participant's ID, group, and other data associated with the participant. Input from this part of this session was analyzed together with participants' interviews at the end of the study. In the interview session, I used a series of predefined questions as a template but the questions were adapted to each case to make the conversation flow.

By integrating a question for experience input into the survey, I wanted to give participants the chance to freely express their comments regarding the conditions, the sleeve's functionality, or their affective state. Unlike the rest of the survey, questions that asked participants to focus only on the sensations of the haptic condition they had just experienced, the experience input question prompted them to compare the sensations to previously experienced haptic conditions. Thus in the experience input responses, the impact of time and sequence of the conditions often becomes very explicit. The question for the experience input was phrased in a way that prompted voluntary rather than obligatory feedback, as my intention was to provide the opportunity for more individualized input. Individual responses in the experience input question vary from no input at all, to one or two sentences per condition, to a full paragraph of thoughts per condition.

The goal of the interview was to investigate more deeply into questions pertaining to the experience of wearing the sleeve. A main topic I was interested in was the association between affective states and haptic conditions. The association of haptic conditions with affective experience provides useful information for the development of the third study pertaining to material mediated interpersonal communication. Another topic I was interested in investigating further was the usability of the sleeve to understand the potential contributions of the research in future applications. Finally, I was interested in participants' evaluation of the UI, which would help improve any study iterations in the future.

I transcribed participants' interviews from audio files, paired them with participants' survey input, and manually tagged them based on certain themes and emergent trends. Some of the main topics emerging from the

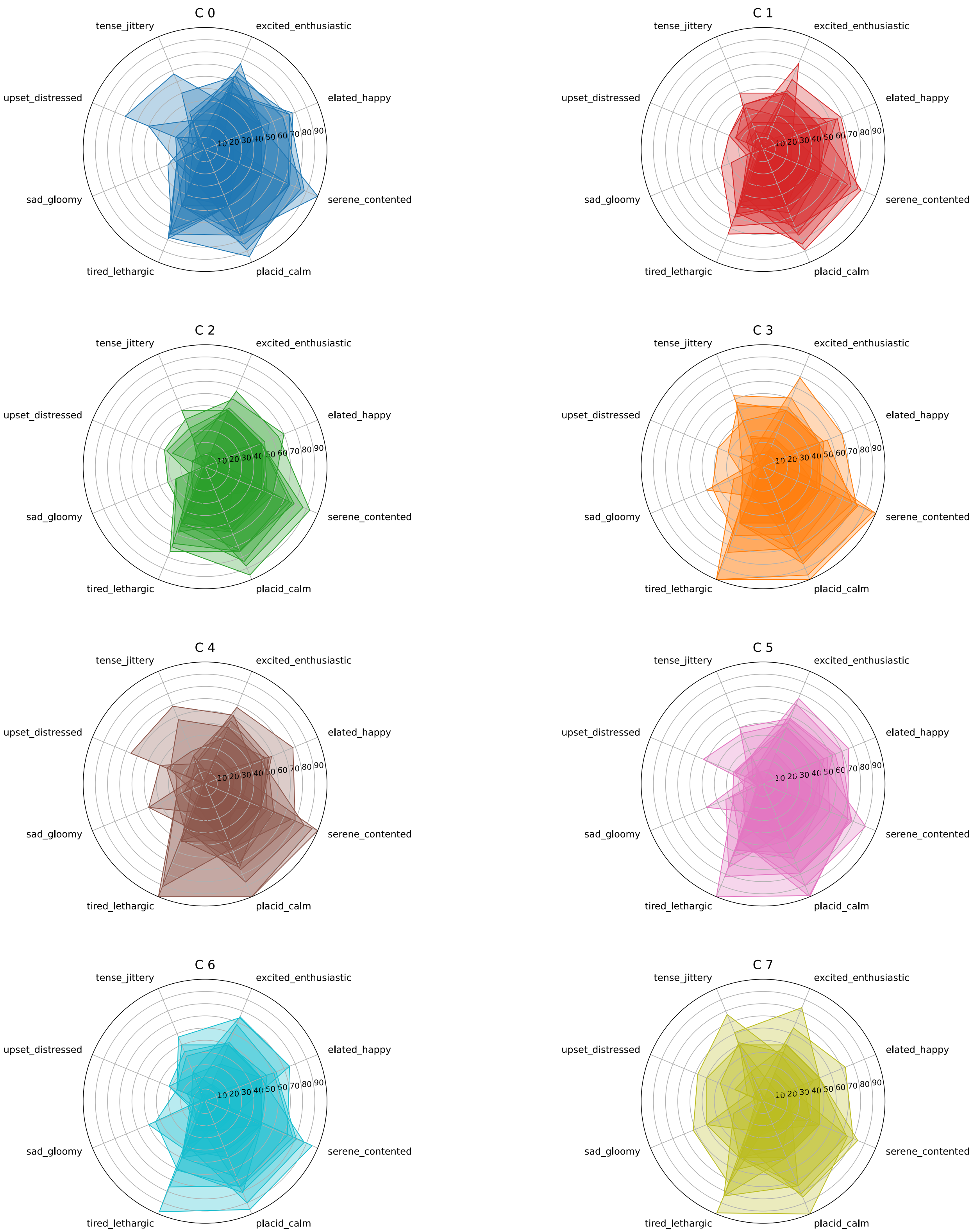


FIG II. 49a
Mood evaluation per condition. All participants of group per condition. Group: Slow group. Number of participants :13

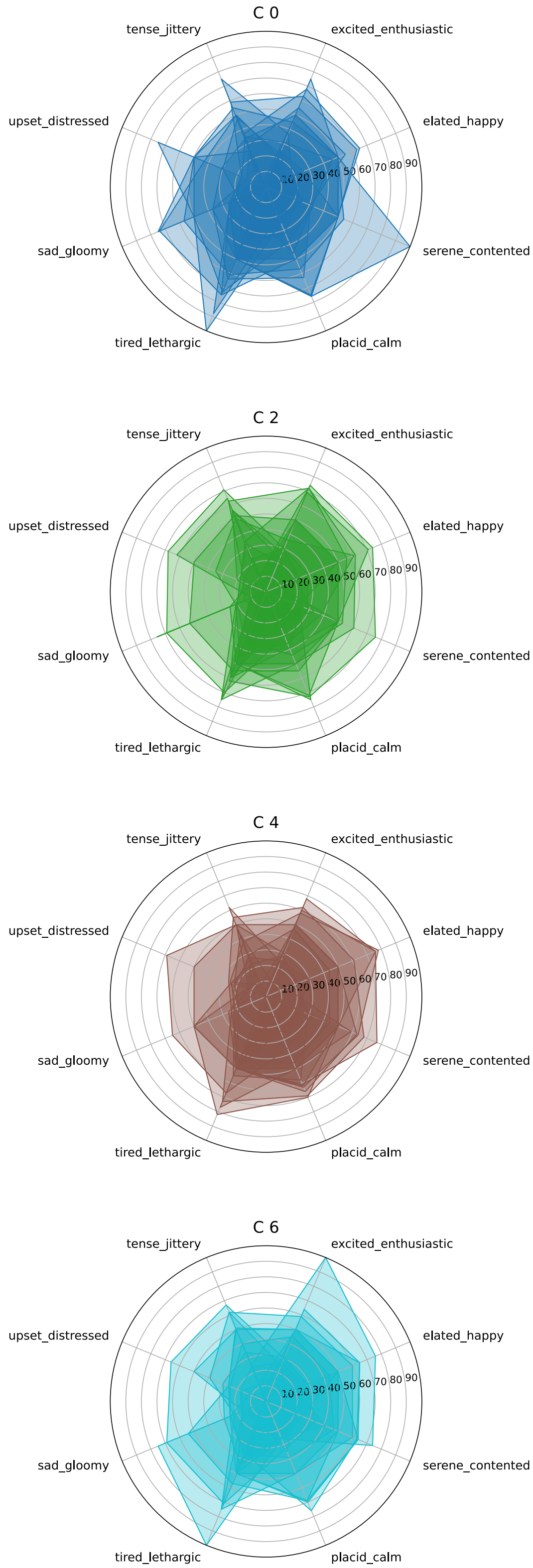


FIG II. 49b

Mood evaluation per condition. All participants of group per condition. Group: Regular group. Number of participants :15

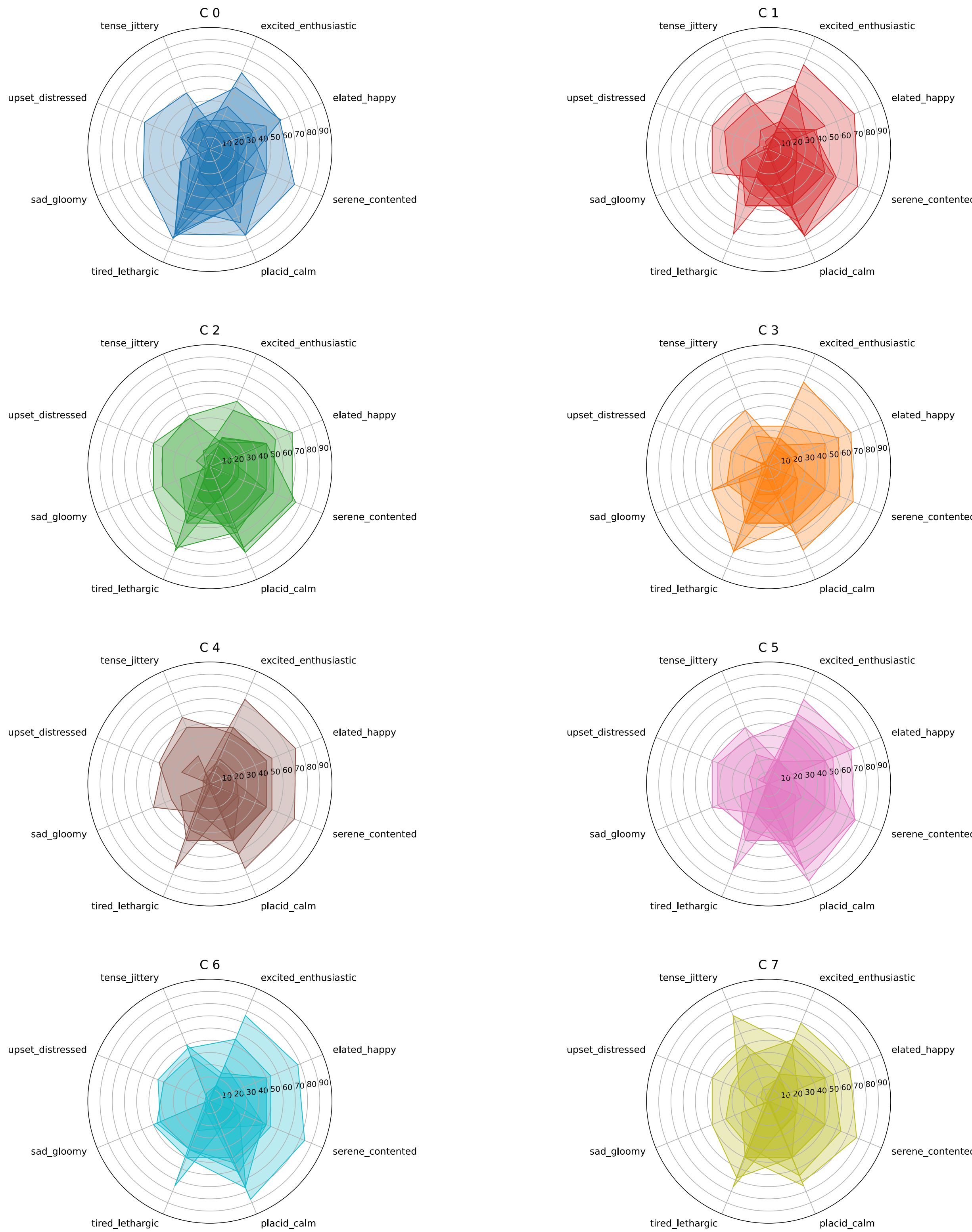


FIG II. 49c
Mood evaluation per condition. All participants of group per condition. Group: Fast group. Number of participants: 8

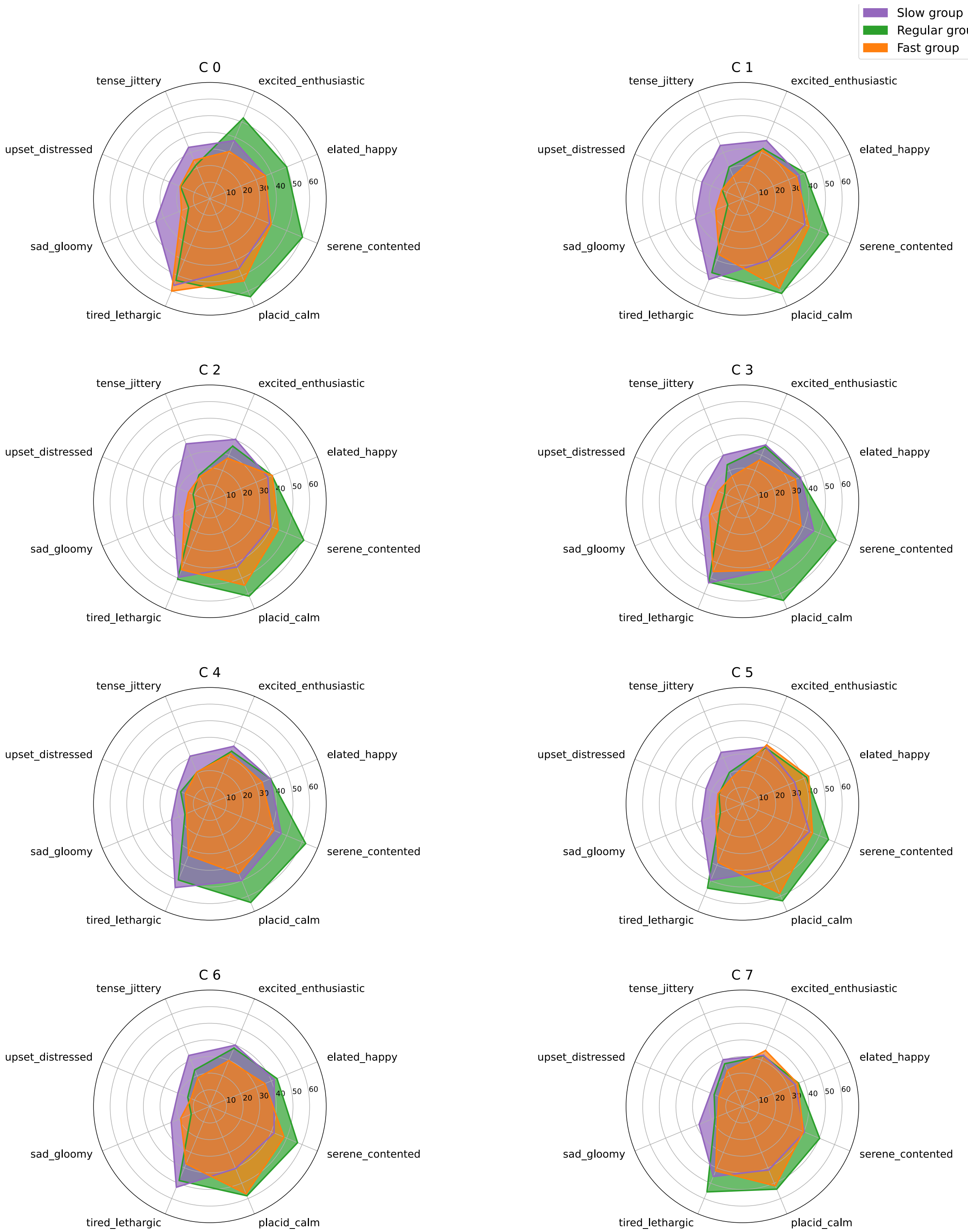


FIG II. 50
Mood evaluation per group per condition.Slow (purple), Regular (green), and Fast (orange) groups

comparison of the qualitative data provided by individual participants or groups are the following: evaluation of haptic conditions and preference of sequential or continuous haptic pattern; preference of heat or pressure and heat combined, and evaluation of sensitivity towards such sensations; impact of the duration and order of haptic conditions in the affective experience and sensory intensity of the haptic action; feedback on possible future conditions that could be implemented; evaluation of the control condition and placebo effects; how cultural associations to the haptic conditions impact their experience and evaluation; evaluation of the sleeve as a potential product and proposed variations by participants; and miscellaneous anecdotal topics.

Interviews and Survey feedback. Experience of haptic conditions. When asked how they felt regarding the experience of wearing the sleeve, many participants discussed how the feeling of different conditions differed. If participants did not explicitly refer to differences between the conditions, they were prompted to identify any differences they felt. Regarding the pattern of haptic action, many participants preferred the simultaneous action of the cuffs over the sequential action of the cuffs or the opposite. Specifically, 11 out of the 36 participants preferred the sequential pattern of haptic action, 9 preferred the simultaneous pattern of haptic action, 4 had an equal preference for both patterns, and 12 did not express a preference. In the Slow group, 3 out of 13 participants expressed a preference for the simultaneous pattern, 2 for the simultaneous pattern, 2 for both patterns, and 6 did express a preference. In the Regular group, 4 out of 15 participants expressed a preference for the sequential pattern, 6 for the simultaneous, 2 for both patterns, and 3 did not express a preference. In the Fast group, 4 out of 8 participants expressed a preference for the sequential pattern, 1 for the simultaneous, and 3 did not express a preference.

Comparing the results, it is interesting to observe that 66% of the participants of the Regular group expressed a strong preference for a specific pattern of haptic action, 62% of the participants of the Fast group expressed a strong preference for a specific pattern of haptic action, and only 38% of the participants of the Slow group expressed a strong preference for a specific pattern of haptic action. These results possibly indicate that the slow pace of haptic action of the sleeve made conditions equally pleasant and smoothed the differences between the different haptic actions; whether the cuffs were activated sequentially or simultaneously did not seem to significantly impact participants' experience of wearing the sleeve. Of the participants who had a strong preference for a pattern, slightly more participants had a preference for the simultaneous over the sequential one. Thus the simultaneous stimulus was the most favorable but also the most disliked among participants.

Of those who had a preference for the sequential pattern, most had a preference for conditions 5 and 6 over conditions 1 and 2. Conditions 5 and 6 have a haptic action cycle equal to a half breathing cycle, whereas conditions 1 and 2 have a haptic action cycle equal to a full breathing cycle. In their implementation, these conditions differ in that in conditions 5 and 6 one cuff is always active, as the sleeve's cuffs activate one after another (once cuff I stops inflating, cuff II starts inflating and so on) whereas in conditions 5 and 6, there is a pause in the cuff activation before the next cycle (cuff II only starts inflating after cuff I deflates). The corresponding pattern to breathing cycle inhalation -> exhalation - > inhalation In conditions 1 and 2 is inflation of cuff (x) -> deflation of cuff (x) -> inflation of cuff (x+1), whereas in conditions 5 and 6 is inflation of cuff (x) -> deflation of cuff (x) + inflation cuff (x+1) -> deflation of cuff (x+1) + inflation of cuff (x+2). When warmth is part of the haptic action (conditions 2 and 6) the feeling of warmth sensations coincides with the feeling of pressure during cuff inflation.

Participants who preferred the simultaneous haptic action, implemented in conditions 3 and 4, often used the metaphor of breath, referring sometimes to the breathing activity of a person or an animal. It is interesting that although all conditions were correlated with participants' breath, participants typically referred to conditions 3 and 4 as reminding them of "breathing" and in only a few exceptions made such association for any of the other conditions. A participant in the Regular group (ID 20) said in reference to one of conditions with the simultaneous haptic action: "there was one that was kind of. . . not in sync with my breath, but it was really like a breath. It was like hearing someone sleeping. . . not actually hearing but imagining someone, feeling someone sleeping next to you." As the participant referred to one of the conditions with simultaneous pattern of haptic action but did not name it, I assume that she referred to condition 4, which also included warmth, rather than condition 3, which only included pressure. Wearing the sleeve apparently felt like the warm touch and breath of a loved one while sleeping.

More than one participant made the association of haptic condition 4 to someone sleeping. A participant in the Slow group (ID 26) provided the following input in the UI regarding haptic condition 4: "The pattern reminded me of someone peacefully breathing/sleeping. Also I came into this study already tired, but I keep falling asleep during it." Another participant in the Slow group (ID 32) wrote in response to condition 4: "the sleeve felt like it was alive and breathing." A participant in the Regular group (ID 42) wrote that condition 3 reminded her "of breathing or holding a cat." A participant from the Slow group (ID 50) chose the feeling of holding a dog rather than a cat to describe the feeling. As she said during the interview: "the experience is very pleasant in general, similar to cuddling with a puppy or something similar. I liked the idea of feeling the pressure, it invokes containment."

Other participants also made reference to conditions 3 and 4 in association with breathing and life. Interestingly, some of the participants mentioned in reference to condition 3 or 4 that they felt that the sleeve was regulating their breathing. A participant in the Regular group (59) wrote in response to condition 3: "I feel the pattern of the pressure sometimes guides my breathing pattern." A participant in the Slow group, wrote in response to condition 4: "At first it was anxiety inducing, but once I was used to the pace of the pressure increase and decrease it became more calming and almost started to regulate my breathing pattern." A few other participants described the sleeve as guiding their breathing or being in synch with the breathing during haptic conditions 3 and 4. The interesting point here is not so much the reference to breathing regulation per se, but the fact that the reference was made specifically for the simultaneous pattern for haptic action.

Participants knew we were using a breathing sensor, and although they were not informed of the intention to make the sleeve regulate breathing (they were informed about the broader study intentions), they might have possibly guessed the intention. The fact that the specific pattern was interpreted in the context of breathing and breathing regulation almost exclusively in conditions 3 and 4, may explain why conditions with the simultaneous haptic action pattern, especially when including warmth, demonstrate a greater relative change of breathing rate than do other conditions. Condition 4, as we saw earlier, demonstrated the highest EDA level change and BR change from baseline. Condition 3 also typically showed higher physiological change than other conditions, but the combination of pressure and heat included in condition 4 showed greater changes, demonstrating that condition 4 is possibly the most effective in regulating breathing and promoting calmness.

One participant of the Slow group (ID 43) thought that the simultaneous haptic pattern was so relaxing that he wished he could feel the sensation all over his body. As he said during the interview, "when it was happening, I was thinking I wished it was happening all over my body; that's what I was thinking. Then I would probably fall asleep." A participant in the Regular group (ID 64) surprisingly anticipated my intentions toward utilizing the sleeve for remote affective communication when she wrote regarding condition 4: "The squeezing of the forearm in harmonic sequence was comforting, and reminded me of when a family member or friend holds a person to let them know that everything will be alright. I could potentially see that the sleeve, if portable, or part of apparel, could be given to someone as a gift from afar and via the internet-of-things, have the sender send a 'hi, I'm right here' pressure tone/sensation, allowing the other user feel closer to that other person despite the geographical distance."

Not all participants felt calm with the pattern of simultaneous haptic action; some found it pleasant but energizing. One participant from the Slow group (ID 50) who described condition 3 as energizing made an analogy between the sleeve and the beating heart. The participant noted that the sleeve's rhythm was "like a heartbeat," and added: "I can imagine this waking me up when I am a bit sleepy, and keeping me active." Participants who preferred the sequential pattern of haptic action over the simultaneous pattern of haptic action often found the simultaneous pattern unpleasantly arousing and anxiety provoking. Interestingly, one of the participants in the Fast group (ID 33) who found the simultaneous pattern annoying also referred to it as a "heartbeat." In the interview, she said that "the one that was all together felt to me almost stressful, the grabbing one, also as it is heartbeat or something, has this rhythm that I don't like much."

A participant in the Slow group (ID 19) who did not prefer conditions 3 and 4 said that it was "like someone was poking you." Some participants who did not prefer the simultaneous pattern of haptic action associated the sleeve with a blood pressure cuff. It is interesting that when the warmth sensation to some extent dissociated the sleeve from the pressure cuff reference. A participant in the Slow group (ID 53) wrote in reference to condition 3: "It reminded me of the blood pressure measurement devices, which makes me think of doctors, so that wasn't necessarily calming. After a while I got used to it, though." Immediately after, in response to condition 4, the participant wrote, "same as before (in condition 3) except the warmth made it more pleasant. When that kicked in I thought less about the pressure being like a blood pressure machine."

Conditions 5 and 6 were more favorable among participants who preferred the sequential pattern than conditions 1 and 2 and said they often evoked the feeling of massage. It is interesting that when referring to the overall impression of the sleeve participants often compared it to the experience of having a massage, when referring to specific conditions they almost exclusively used the massage reference for conditions 5 and 6. After experiencing condition 5, a participant of the Regular group (ID 25) wrote, "5: I enjoyed this session more than previously (condition 3); it felt like a nice massage on my arm, moving back and forth." A participant in the Slow group (ID 53) said in relation to conditions 5 and 6, "it felt like a massage, it reminded me of a Swedish massage when it was doing the upward thing" and added in response to the simultaneous haptic pattern in condition 3 and 4, "The all-together pattern reminded me of the blood pressure machines which is kind of distracting."

With regard to the sequential pattern of haptic action, most participants distinguished between the conditions with a haptic action matching a full breathing cycle (conditions 1 and 2) and conditions with a haptic action matching a half breathing cycle (conditions 5 and 6). As previously mentioned, conditions 5 and 6 evoked the feeling of having a massage and were the most favorable among conditions with sequential patterns. Conditions 5 and 6 were perceived as more continuous and natural than conditions 1 and 2, which were perceived as “jumpy” (ID 22, Slow group) and often as anxiety-provoking. Participants who expressed a preference for the simultaneous pattern of haptic action over the sequential one, experienced conditions 1 and 2 as the most distressing. A participant of the Slow group (ID 26) said: “I noticed that I liked more the ones with gradual transition, it threw me off when one single cuff was going of at a time, when there was multiple ones going off it felt better, either all the sleeve at once (conditions 3 and 4), or one at a time but gradual (conditions 5 and 6) Those ones were the nicest ones.”

Some participants who did not prefer the sequential pattern mentioned that the sequence and direction in the haptic pattern was anxiety provoking. The anxiety was produced because of the anticipation of the next cuff being actuated and the awareness of the repetition of the same sequence of action. One participant of the Regular group (ID 21) associated this repetitive feeling with hearing a phone’s annoying ringtone. During the interview, he said the following:

> “The one [condition] that felt more calming was definitely the one that was all at one, rather than in sequence. The sequence more indicates something, a direction or a motion or something. Having the expectation that something will happen was different. The fact that there is a pattern happening again and again, so it becomes annoying, it’s like the phone ringing again and again - a pattern that you expect to hear again, like a ringtone, the first time is fine but then is annoying. Whereas the one that has the whole sleeve felt soothing, it just kept going and didn’t feel like a rhythm as much, it was more like a chord rather than a rhythm.”

Other participants made negative remarks only in reference to conditions 1 and 2, stating conditions 5 and 6 felt more natural, pleasant and massage-like. For example a participant of the Slow group (ID 32) noted, “the ones that were separate (conditions 1 and 2) were not as nice as the other ones. Because they were not doing a massage, it was more like the thing breathing on its own. It was nice to see it but the feeling was not as nice as the other one.” This participant interestingly associated all conditions but 1 and 2 with massage, and all conditions with breathing, remarking that unlike all other conditions in conditions 1 and 2 the sleeve “is breathing on its own’’ possibly implying that in the rest the sleeve is synched to his breath.

For a participant in the Regular group (ID 62), conditions 5 and 6 felt relaxing, while conditions 1 and 2 felt more energizing. Participant 62 said she loved the smooth transitions of condition 5 and 6 where the sensation felt as if they were traveling all over her body. In the interview she noted, “you know there were times that I would feel the pressure more directed to a specific spot than uniform – so the ones that were to specific spots rather than uniform, felt more like transferring to my whole body in a sense. When you feel for example goose bumps and you kind of feel it like that (like tingling sensations).” In the UI input, she noted that conditions 1 and 2 felt more intense and energizing. It is interesting that this participant mentioned a feeling of tingling sensation transferred to the whole body, as this is one of the feelings one experiences in breathing meditations practices.

The idea of transferring the location of haptic action from one spot to the next, implemented in the sequential haptic pattern, explained in the context of Study I [chapter 3.1], was inspired by the practice of body scanning meditation; thus I was excited to observe the experiential association made by participant 62. During the body-scanning meditation practice one transfers their attention to adjacent locations of the body, a method that leads to greater body awareness and eventually relaxation. Other participants noted that the sequential haptic action made them transfer their attention to the different locations of the forearm but that the experience was not relaxing because it required them to direct their attention. A participant in the Regular group (ID 42) reported in reference to the haptic conditions, “So the one that seemed the best and I liked the most was the one that inflated all the sleeve together at once, because the one that was inflating sequentially made me put more attention to it, notice it a lot more.”

Another participant of the Regular group (ID 21) wrote in response to condition 2, which he evaluated as the least pleasant condition: “I could precisely feel it in certain areas, the same sensation of someone touching you (with a very warm hand). It seemed to try to grab my attention or specifically point to something ‘look at your wrist, or ‘observe your bicep’.” Perhaps one should wonder at this point if awareness and mindfulness necessarily equates to relaxation. In beginner meditation classes, for example, it is common for practitioners to feel unnerved and uncomfortable. Perhaps wearing the sleeve for a longer time would change these perceptions. Another emerging question is --if the purpose of the sleeve is to gradually transfer the attention from one location to another-- whether the forearm is the best part of the body to do so.

As mentioned, regarding the sequential pattern of haptic action, most participants preferred conditions 5 and 6 over conditions 1 and 2, which they experienced as unnerving. A couple of participants, however, preferred conditions 1 and 2 over 5 and 6, as they perceived these rhythms as being slower and felt that conditions 5 and 6 were less relaxing and more arousing. Interestingly, the sequential rhythm which to some seemed as annoying as a repeated ringtone to others felt fun and playful. A participant from the Regular group (ID 29) noted in the interview that, “In the cases that I felt my whole arm being warm, in those cases I felt more weird in away, not stress but pressed, in the sessions where pressure and warmth was simultaneously in all locations, I would feel not so pleasant in a way. Whereas when pressure and heat was more distributed, it was more smooth, it felt more pleasant, almost like a toy, a playful sensation” This participant added that when the sequential pattern was faster, in conditions 5 and 6, the sensation was less relaxing.

The “playfulness” of the sequential pattern was also noted by another participant indirectly, who noted that the sleeve felt like a xylophone. The participant who was part of the Slow group (ID 53) first noted that the sequential pattern felt like a “Swedish massage up and down,” and then added “I can’t think of anything more relaxing that the kind of xylophone up and down.” Here it is interesting to note that the participant had the illusion (or misperception) of the rhythm going up and down, as the pressure and warmth always had the same direction from the wrist to the elbow. The choice of the xylophone metaphor is fascinating because like the sleeve, a xylophone is composed of several distributed pieces; in the case of the xylophone each piece produces a different note, while in the case of the sleeve it produces a different perception of the produced haptic action. The sensation produced by each of the xylophone pieces is different --and the perception of the haptic action of each sleeve’s cuff is different-- not because of their materiality and the way they are actuated but because of their location and size.

The idea that the sleeve has some sort of musicality associated with the rhythmic haptic sensations was also expressed by a participant in the Slow group (ID 50), who thought of the patterns of haptic action of the sleeve as equivalent to musical rhythms that can be relaxing or energizing. When asked if she would wear the sleeve if it proved to improve her wellbeing, the participant responded as follows:

> “Yes, definitely. Some of the rhythms make me feel active, faster and based on pressure, so that is something I would definitely try when I am sleepy and tired and want to be more active and productive. It reminds me of when I listen to music, active music, when I am tired and I want to work, so those rhythms like faster and pressure based made me feel like that, that I would use it. And also for calming, for meditation and for falling asleep.”

Noting that the fast pace is more energizing than the slow pace is consistent with the results of the survey sliders regarding affective states: participants of the Fast group felt on average more excited and energized than the Slow group who felt on average more calm and tired. Of course the participant discussing the sleeve's rhythms in regard to music and activity only participated in one group, thus the comparison does not directly refer to the different paces of the groups. However, the participant did experience two different paces of haptic action, if one interprets the difference in the cycles of conditions 1, 2 and 5, 6 in such a manner. Other participants also experienced conditions 5 and 6 as being faster than 1 and 2. Even though each cuff individually was pressurized for the same amount of time, the transition time between the actuation of the cuffs twice as fast in conditions 1 and 2 than in conditions 5 and 6.

Interviews and Survey feedback. Experience of warmth and pressure sensations. Regarding the experience of warmth in the conditions, 19 out of the 36 participants explicitly said in the interview that they liked the warmth of the sleeve, or the combination of warmth with pressure, and many of them reported that warmth felt calming. Only 8 participants explicitly said that they did not like the warmth. The remaining 9 participants did not make any positive or negative comments regarding the sensation of warmth. Out of the 19 participants who made positive remarks about the experience of warmth, 10 were participants of the Regular group, 5 were participants of the Slow group, and 4 were participants of the Fast group. Out of the 8 participants who made negative remarks regarding the experience of warmth, 2 were from the Regular group, 3 from the Slow group, and 2 from the Fast group. Overall participants liked the warmth sensation and usually characterized warmth as being relaxing. A participant of the Slow group (ID 26) noted, “The ones with heat I enjoyed more, it was just the right temperature, very peaceful….”

A few of the participants who liked the warmth noted that they would have liked it to be more intense. For example, a participant of the Regular group (ID 23) noted that “the (conditions) with warmth were more relaxing and she would crank up the heat.” Other participants who liked the warmth thought that it was at times too intense. For example, a participant in the Fast group (ID 30) reported, “I liked the gentle heat, I almost fell asleep. Other times that the heat was intense around the wrist I didn't like it as much.” Participants did not always feel the warmth as being equally distributed along the cuffs. The experience of warmth also varied depending on the condition. It is interesting that a participant who reported not being sensitive to heat because he had grown up in a warm country, noted that he did not feel much warmth in the conditions except for condition 4, where he reported feeling intense warmth that made him sweat (ID 27 Slow).

The few participants who did not like the warmth reported that it felt either intense or strange. A participant of the Regular group (ID 25) noted, “the heat for most of them I feel like I didn’t notice it (referring possibly to the conditions with no warmth), and when I did notice, I thought it was strange, I thought I am sweating underneath, it felt weird, more intense than a heat pad.” Another participant noted that the warmth was unpleasant because he was wearing a thick sweater (ID 32 Slow), and another one that it felt “strange and unnatural” (ID 33 Fast). Finally, a female participant noted that the warmth felt intense because she was pregnant and for this reason more sensitive to warmth (ID 26 Slow).

Regarding the experience of the pressure sensation, participants typically did not enjoy as much the conditions that included pressure only because they compared them with the ones that also included warmth, which they enjoyed more. A participant in the Regular group (ID 64) who experienced condition 1 third in the sequence, after experiencing condition 7 and 4 wrote in the UI, “I liked the pressure sensor, but since I was already introduced to the warmth in the previous session, I preferred to have warmth accompany the experience.” Another participant (ID 17 Regular) who really enjoyed the warmth said that the patterns that did not include warmth were disappointing. As he noted during the interview: “some of the patterns were disappointing, for example after the one that was incremental with temperature, the other one was also incremental and did not have temperature and I was disappointed because I liked the warmth. . Sometimes I would wonder, what happened to the warmth? It was so nice and now it is gone.”

In total, 5 participants said that the pressure felt too much or too intense and they would prefer less. Of those 5 participants, 4 were in the Regular group and 1 in the Slow group. An additional participant of the Regular group (ID 28) noted that she liked the pressure only when it was combined with warmth because “when it was only pressure it felt like a blood pressure cuff, so it had this medical connotation” which made her a little “uncomfortable and tense.” One participant (ID 20 Regular) who did not enjoy the pressure sensation compared the sensation to that of warmth, even though warmth was never experienced alone as a sensation. In the interview she noted that “pressure was in some ways always stressful, whereas heat always felt nice. Heat felt like someone was just touching you; it never felt alarming like the pressure, which felt aggressive.” Interestingly, for another participant (ID 65 Slow) the sensation had the opposite effect: the feeling of pressure took his mind off his worries but the sensation of warmth made him aggressive. During the interview he noted, “heat in general makes me more aggressive, certain feelings of mine like annoyance get amplified for me with heat.”

The sensation of pressure was usually not evenly perceived. Out of the

36 participants, 13 noted that they felt the pressure more intensely on the wrist. Out of the 12 participants, 4 were in the Regular group, 4 in the Slow group, and 3 in the Fast group. Some of the participants also noted feeling more pressure on the fifth cuff, close to the elbow, and a few noted that the pressure decreased in the middle of the sleeve. The increase in intensity in those two end-locations -- and especially on the wrist -- align with the results of the survey on the self-assessment of experienced intensity of the sensations. Many participants mentioned they enjoyed the feeling of pressure in all areas but the first cuff, where it felt more intense. Regarding conditions 3 and 4, some participants mentioned the middle cuffs as being more intense; a few stated that they only felt pressure in the two middle cuffs of the sleeve. These reports also align with the self-assessment of intensity of the felt sensations, as in conditions 3 and 4 intensity was marked as being higher in the middle cuffs. It is important to note here again that the amount of pressure and warmth on each cuff was the same in all conditions, and that it was the perception of the haptic pattern that changed the perception of the felt sensory intensity along the forearm.

Although warmth was intensified by pressure because of the sleeve design, it is interesting that participants did not typically experience warmth as being intense on the wrist although they did mention that warmth increased and increased in correlation with pressure. On average, the sensation of pressure felt more intense than the sensation of warmth but the threshold of comfort differed among participants: some were less and some were more sensitive to warmth or pressure. A participant in the Regular group (ID 64) mentioned that the more pressure, the more relaxed she felt. Similarly inclined towards intense pressure, a participant in the Slow group (ID 50) said that she liked the idea of feeling the pressure because it made her feel more “contained” and more “solid.”

Warmth and pressure sensations often differed in regard to the granularity of perception; one sensation felt for some more gradual and continuous than the other. A participant in the Regular group (ID 59) described her experience as follows: “I felt that my perception towards pressure was more sensitive than towards warmth because maybe warmth is kind of gradual, our body senses it gradually and (it) goes away gradually, not immediately.” A participant of the Fast group (ID 44) had almost the opposite experience, as for her the pressure sensation was more nuanced than the warmth sensation. She noted, “I think I could also feel the pressure variance, but I felt . . . the amount of pressure was easier to read than the temperature. The temperature felt more like a binary on/off thing whereas the pressure was more nuanced in its perception.”

Interviews and Survey feedback. Impact of time. Many of the participants reported that their experience changed throughout each session. For some, one or both of the sensations of warmth and pressure intensified within a haptic condition. This intensification of the sensation could be a physiological response or psychological response as a result of the continuous and repetitive haptic pattern, which seems to create the expectation and misperception of gradually increasing sensations. For example, a participant of the Regular group (ID 42) noted in regard to the felt sensations, "I liked the pressure better than the heat; you can feel the heat warming up, but then when it's strapped to your arm, you get the feeling, oh it strapped me and if it is gonna get too hot?' Another participant (ID 26 Slow) reported that in condition 5, "I enjoy the haptics with high pressure, it's almost like a massage, I like the feeling. But it's a double-edged sword because when it's really tight, though it's a cool feeling, I subconsciously worry about the pressure never decreasing and getting tighter and tighter and not stopping."

The levels of pressure and temperature always remained the same throughout the condition. However, in participants' subjective experience, the sensations often became more or less intense over time or were reported to gradually increase and then decrease. A participant in the Slow group (ID 43) who had a cyclical perception of warmth during each session, noted, "The way heat comes one, it comes from gradual then intensifies and then decreases, I wish it stayed at the middle level all the way." Feelings also changed throughout the study. Some participants felt anxious at first but then became used to the sensation and eventually became more relaxed. A participant in the Regular group (ID 28) noted, "I honestly thought there would be kind of an electrical shock [laughs]. . . . When I realized the range of the produced sensations, I felt kind of relaxed." Surprise and excitement among participants would typically subside, and for some participants become a relaxing sensation. One participant of the Slow group (ID 41) noted, "Just doing it a lot, I just felt more chill."

It is interesting to observe how one participant's (ID 41 Slow) affective state moves from excitement and curiosity to tiredness and relaxation. His comments on the UI survey follow the order the conditions were experienced:

> Condition 6: It feels interesting, a little weird but fascinating.
>
> Condition 1: This was softer and less hot.
>
> Condition 2: Very hot and pressure strong but still less intense than the first one.
>
> Condition 5: Definitely felt my heart rate feeling very chill and tired, not sure if it is this or mood in general.

> Condition 7: Nothing happened this time that I could feel.
>
> Condition 4: Whole arm was nice. soothing and less intense than the other
>
> Condition 3: The pressure was more full on but it was good. Feeling very sleepy.

Other examples start to show a peak of pleasantness in the middle that becomes more negative towards the end. For example, it is interesting to observe how the perception of the haptic pattern in conditions 5 and 6 changed through time. The same haptic pattern of pressure that was felt first in condition 6 and as not being pleasant was reported in condition 5 as being very pleasant. A participant in the Fast group (ID 33) provided the following comments in the UI:

> Condition 6: Neutral. The pressure was almost pleasant in the areas of IV and V but a bit too much in I and II.
>
> Condition 7: I didn't feel anything.
>
> Condition 2: Better than the first one. The warmth level felt better and the pressure.
>
> Condition 5: Felt like a massage.Very pleasant.
>
> Condition 1: I prefer the previous one because the transitions were faster and it felt like massaging.
>
> Condition 3: It was a bit annoying. Felt like a heartbeat so it was kind of stressful as well.
>
> Condition 4: I think I don't like the uniform pattern movement. Also, I prefer only pressure.

A cyclical mood during the session was explicitly expressed by a participant (ID 62) in the Regular group, who confessed the following:

> "Initially when I first arrived I was kind of stressed, so the first sessions kind of relaxed me . . . but during the time of the next sessions, I don't know why this feeling wasn't preserved. So then I started feeling more energized and then I got back to that stressful feeling I was in the beginning. It did not feel gradual towards some kind of experience, for me it was ups and downs."

Her comments regarding the seven conditions, in the order they were experienced, follow here:

> Condition 3: It was calming and relaxing.
>
> Condition 2: It was following a regular pattern of sensations and felt like it was increasing in warmth and pressure in each iteration. I liked the level of warmth and pressure and I liked that it felt more intense than the last time. It felt energizing.
>
> Condition 5: More relaxing sensation than the previous one and it felt like the sensation was transferred to the rest of the body.
>
> Condition 7: I got this slight sensation that I am not sure whether it was coming from the sleeve or my hand moving.
>
> Condition 4: It was different than the others, the pressure sensation felt more uniform and it did feel pleasant but it was kind in the middle of relaxing to energetic that I was getting from the previous ones.
>
> Condition 1: I enjoyed the pressure but the lack of warmth made it feel less intense as an experience.
>
> Condition 6: No Input.

Some participants felt progressively more tired throughout the sessions, and feelings of pleasantness progressively decreased. A participant of Regular group (ID 25) noted in the interview, “ The more sessions you do the more tired you get; sessions that felt nice in the beginning felt a bit tiring in the end.” One participant commented as follows:

> Condition 1: The heat was fairly unnoticeable, and the pressure was both pleasant and unpleasant... a bit like a strange massage.
>
> Condition 3: As the session progressed the pressure became more unpleasant and a little worrying, or stressful so to speak
>
> Condition 5: I enjoyed this session more than previously; it felt like a nice massage on my arm, moving back and forth.
>
> Condition 7: I didn’t feel anything.
>
> Condition 4: I noticed the heat the most out of all sessions but it made me feel a bit strange or uncomfortable; the pressure was

> also a bit unpleasant - mostly the build up of the pressure over time which is a bit unpleasant throughout all the session.
>
> Condition 2: Again, a bit unpleasant in the edges as the pressure would build up. the warmth is equally strange, both pleasant and unpleasant at the same time; In general I'm beginning to feel tired of the study.
>
> Condition 6: I notice that I enjoy the pressure more when it moves fast from one cuff to another, but again, after a while the pressure begins to be unpleasant and makes me uncomfortable.

Interviews and Survey feedback. Experience of the control condition. The participants' input revealed some of the reasons why condition 7 (control) produced the results reviewed earlier in the EDA and BR measurements. One reason why the EDA and BR levels demonstrated an increase in some cases may be that as revealed in the interviews, participants felt stressed and restless during the condition. In some cases, the inactivity of the sleeve produced restlessness because participants could not tolerate "just sitting" there. For example, a participant of the Slow group (ID 34) noted regarding condition 7, "Time feels extremely long. Feels stressing and boring lol." Another participant (ID 60 Fast) also felt very stressed from doing nothing. He noted in the UI regarding condition 7, "I was unnerved by no sensation and very aware of my body, the weird position my elbow was in, etc." Another other reason why some participants may have felt stressed during condition 7 was that they thought that the sleeve's inactivity was because of the system not working properly. For example, a participant in the Slow group (ID 32) wrote in response to condition 7, "Nothing was going on, so I thought the machine was broken or something."

Another interesting observation regarding condition 7 was the apparent placebo effect that sometimes made participants feel -- or wonder if they felt -- warmth, pressure, or both sensations. Out of the 36 participants, 7 participants reported in the interview or UI survey that they felt either a pressure or warmth sensation during condition 7. A participant in the Slow group (ID 26) tried to figure out if the sensation was real or imagined. She noted in the UI survey, "I can't tell if I imagined the pressure, it felt like super faint pressure was slowly/gradually increasing, but I might've been imagining it." The order of the conditions possibly affected any placebo effects. In the case of participant 26, condition 7 was experienced third, after conditions 3 and 6. It is, however, interesting that the specific participant's "haptic sensors" were in general a bit inaccurate, as she not only questioned the sensations of condition 7 but also the warmth of condition 3. Regarding condition 3, which she experienced first in sequence, she said, “I can’t tell if I thought the warmth was its own thing or that my brain thought pressure was warmth.”

Perhaps one of the most interesting testimonies regarding condition 7 was given by a participant in the Regular group (ID 59), who experienced it first in the sequence of conditions in the study. She first wondered what happening, as she was not feeling the sensations she thought she was supposed to feel. Eventually she convinced herself that she gradually felt more warmth. In the interview, she pointed out to me that “the session that has warmth only, I didn’t expect it, I was like hm what’s happening? And then I felt a little bit of warmth and realized it was only the warmth that was happening.” Regarding condition 7, she noted in the UI: “I was expecting pressure together with warmth in the beginning. Then after a few seconds, I figured it was only warmth happening. It was happening in a gradient.” Another participant (ID 62 Regular)) was trying to figure out if the sleeve was moving or if she was hallucinating. In the UI, she commented on condition 7 that “I got this slight sensation that I am not sure whether it was coming from the sleeve or my hand moving.”

In addition to the reported hallucinatory effects evoked by condition 7, participants’ subjective perception regarding other conditions also varied. For example, conditions with a sequential pattern of haptic action were sometimes perceived as having varying speeds. One participant noted that “all conditions felt as having different speeds” (ID 21 Regular). Other participants seemed to have a different perception of pressure when warmth was present. For example, one participant (ID 29 Regular) noted, “I realized that when pressure is put on cuff I and then sequentially on cuff 2 and 3 and so on, I thought that warmth was more intense in this session.” The same participant made the observation that she felt the pressure coming from different directions depending on the session. She noted in the interview, “I don’t know if there is a difference in the way the pressure was put. So in some sessions I felt that the pressure was coming vertically and in other sessions I felt that the pressure was coming from the sides.”

Interviews and Survey feedback. Input on the study and potential applications of the sleeve. As my intention was to understand the association between different haptic conditions and affective states, I integrated a question into the interview asking participants to provide any feedback on haptic conditions that they would want to experience or conditions that would make them feel very differently from the way they felt during the study. In response, some of the participants noted that it could be anxiety provoking to have a sleeve with random or unpredictable directions in the cuff activation and intensity of sensations. For example, one participant (ID 42 Regular) noted, “Random - make it very random, so you don’t know the order, or maybe if there is a way to make order and duration random so you don't know how long or where, that would be totally anxiety inducing. Because (the experienced conditions) were all relatively ordered." One participant (ID 60 Fast) gave an especially creative response to my question: "I would design something emulating someone pressing my arm. Maybe two or three at a time and shifting around. I might feel more interested overall when engaging more sensors at the same time, in different modes."

In the interview, participants were asked if they would be willing to wear the sleeve if it could improve their wellbeing. In general, participants were more prone to wear the sleeve if they were already using devices or garments to improve their wellbeing or were involved in other wellbeing practices. For example, a participant in the Regular group (ID 28) responded: "Yes - I like to try stuff like that. I do acupuncture and I believe that there is a body-mind connection." Another participant (ID 50 Slow) commented, "I have to wear these compression tights because of the blood circulation, it makes feel more solid, it makes me feel like that, so it's kind of a good feeling and I like to try it in other forms, as a suit or vest or on the legs. One participant (ID 43 Slow) responded, " Yes - Oh yes, I would wear a suit, go to work and if I need a break I would take a full body massage." Other participants said they would wear it but only at home.

Finally, when asked if they would wear the sleeve, some participants came up with ideas for other applications. For example, one participant (ID 59 Regular) proposed a function similar to that of health tracking smartwatches that slightly vibrates to remind the user to move around so as not to sit for too long. When I asked her if she would wear the sleeve, she responded, "Yes, for massaging purposes or to remind people to move a little bit "Oh you have been sitting here for too long' (laughs)" Another participant (ID 53 Slow) said he would wear the sleeve (in the form of pants) to improve blood circulation while traveling on an airplane. Finally, one participant (ID 44 Fast) elaborated on how the sleeve could have the functionality of a smartwatch but in a more distributed and less intrusive manner. When asked if he would wear the sleeve, he responded in the following way:

> "Yes. I would prefer it over an apple watch. In one arm or even both, like a google maps that gives you directionality, or something for notification, maybe one cuff is email, maybe another sms notification, maybe this is less intrusive than a watch with a screen that constantly distracts you also. Maybe you could even choose the amount of rings, you know, up to five. Maybe you know if you wanted only notifications you could do that, you know each unit can have its own purpose, or you can start from one unit and then add complexity. And I think it's a good idea to have it on your arm, I wouldn't want to have it on my head, on my throat or on my legs!"

3.2.4. CONCLUSIONS

A controlled study with 36 participants was conducted to test the psychophysiological impact of a programmable pneumatic sleeve with haptic action. The study included the testing of seven conditions: six conditions of haptic action (haptic conditions) producing rhythmic patterns of pressure or pressure with warmth, and one control condition in randomized sequence. In the control condition participants were still wearing the sleeve but the sleeve produced no haptic action. Subjective evaluation data were collected from a User Interface (UI) and physiology data were collected from sensors measuring participants' breathing rate (BR) and electrodermal activity (EDA).

Two hypotheses were tested in the study, formulated as follows: (1) the pace of the sleeve's haptic action has a positive correlation with the wearer's breathing rate and a negative correlation with the wearer's perception of calmness; (2) distinct conditions of haptic action (haptic conditions) can be associated with distinct affective states. A Fast, Regular, and Slow group were included in the study; the pace of the Fast group was 30% faster than participants' relaxed breathing rate; the pace of the Regular group was equal to participants' relaxed breathing rate, and the pace of the Slow group was 30% slower than participants' relaxed breathing rate.

3.2.4.a. PHYSIOLOGICAL DATA

Electrodermal Activity. Both the electrodermal activity levels (EDA-L) and the electrodermal activity fluctuation response (EDA-R) were calculated. A comparison of relative change EDA-L from baseline for each condition and a comparison of the absolute change in EDA-R from baseline for each condition demonstrate the following: higher arousal levels and response fluctuation for haptic conditions with patterns of simultaneous haptic action compared to conditions with sequential haptic action; higher arousal levels and response fluctuation for haptic conditions including both pressure and warmth compared to conditions including only pressure; no important differences between the different groups in regard to the response to specific conditions; unexpected results in the control condition with the Fast group demonstrating higher EDA-L and EDA-R than the Regular group, and the Regular group demonstrating higher EDA-L and EDA-R than the Slow group, where similar EDA levels and fluctuation response were expected.

Using linear regression, I calculated the change of EDA levels within each condition by using the slope of a first-degree polynomial. The mean EDA levels change (slope) for each condition show that on average participants of all three groups demonstrate a decrease of EDA levels from the start to the end of condition. A comparison between the EDA levels change (slope) of the Slow, Regular and Fast groups demonstrates that the average decrease of EDA levels (slope) in the Fast group is approximately double that of the decrease of EDA levels (slope) in the Slow and Regular groups. A comparison between the EDA levels change (slope) within each condition and after each condition (within the duration of each condition's succeeding survey) demonstrate a decrease within the condition and increase after the condition.

Continuing the analysis of the change of EDA levels (slope) within and after each condition (during the succeeding survey), a comparison between the three groups demonstrates that in the Slow and Regular groups the amount of decrease during the conditions is typically greater than the amount of increase after the conditions; in the Fast group the amount of decrease during the condition is approximately equal to the amount of increase after the condition. The amounts of increase and decrease in the Fast group are much greater than the amounts of increase and decrease in the Slow and Regular groups. In the control condition, we also observe a decrease and increase of approximately equal amount, during and after each condition, respectively.

The comparison of the relative change in EDA levels from baseline (EDA-L) of all participants in each group -- in the true order conditions were experienced based on the randomized sequence -- provides information regarding the overall impact of haptic action over time, regardless of the specific conditions. Such comparison demonstrates that the mean EDA levels increase consistently from the first to the last condition, with values of the Regular group being slightly higher than those of the Slow and Fast groups [see Appendix]. The average difference in EDA response fluctuation (EDA-R) from baseline of all participants, in the true order conditions were experienced, has a pattern closer to a waveform, with alternating peaks and values from the first to last condition. A comparison between the change of EDA levels within conditions (slope) in the true sequence they were experienced, for each group, shows an increase over time, which is more evident in the Fast group, whose values are lower.

Finally, a comparison between the change in EDA levels within conditions (slope) during and after the conditions (within their succeeding surveys) in the true sequence they were experienced, demonstrates a decrease during the condition and increase in the succeeding survey. In the Slow and Regular groups the absolute value of decrease is higher than that of the absolute value of increase and the difference becomes smaller in the last conditions. In the Regular group, the absolute values of positive and negative slope for the condition and survey progressively increase until the fourth condition and then decrease. In all sessions of the Fast group, the absolute values of EDA levels decrease during the condition and increase after the condition are approximately equal.

Overall, the results demonstrate that conditions with simultaneous haptic action and combination of pressure and warmth cause on average an increase in arousal levels; however, this measurement does not reflect their effectiveness in reducing arousal levels within conditions. The mean EDA levels and response do not noticeably differ in regard to the pace of haptic action. The impact of different conditions regarding reducing arousals within the condition slightly differs in regard to the pace of haptic action. Results from EDA levels change (slope) within conditions suggest that a pace of haptic action slower or equal to one's relaxed BR has a longer impact on one's physiology -which might promote relaxation- compared to a pace of haptic action that is higher than one's relaxed BR – which might be energizing in the short term.

Overall, the results demonstrate that results of changes in EDA are also impacted by the duration of the study. Results from mean EDA levels demonstrate that experiencing the haptic action of the sleeve for longer durations contributes to an increase of average electrodermal activity levels. The results of EDA fluctuation response over time demonstrate a different pattern than do average EDA levels over time: response seems to reach peak levels and then subside within the duration of study. These EDA results possibly suggest that average levels increase over time because of increased perspiration but that response due to psychological arousal varies during the study, with positive and negative peaks.

Breathing Activity. A comparison between the three groups of participants' relative change of breathing rate (BR) from baseline demonstrated the following: a 4.79 % on average decrease in the participants of the Slow group, a 2.08% on average decrease in the participants of the Regular group, and a 7.20% on average increase in the participants of the Fast group. These results are aligned with my hypothesis, as they demonstrate that participants' breathing rates increase or decrease according to the pace of haptic action of the sleeve; a slow pace will cause decrease and a fast pace will cause increase. In other words, the pace of haptic action seem to be positively correlated with participants' breathing rate. The broad distribution of the data revealed through the calculation of error bars suggests that these results are not statistically significant.

A comparison of participants' relative change of BR from baseline between the different conditions demonstrates that the conditions causing the highest change in breathing rate are haptic conditions that include both warmth and pressure, not conditions that include only pressure. The results also demonstrate that conditions with simultaneous activation of the cuffs with pressure alone caused roughly twice the amount of change in BR than do conditions with sequential activation of the cuffs with pressure alone. Such results demonstrate that conditions including both warmth and pressure, and conditions with simultaneous activation are more effective in regulating breathing. The results of the control conditions are, like those in the EDA analysis, unexpected, as they are aligned with the overall tendency demonstrated in the rest of the conditions.

3.2.4.b. SELF-REPORTED DATA

Perception of sensations produced by the sleeve's haptic action. In conditions including both warmth and pressure, all participants recognized and distinguished both sensations. In conditions including only pressure, a small percentage of participants also reported feeling warmth. In the control condition, a very small percentage of participants reported feeling warmth and/or pressure. With a few exceptions, each sensation was perceived as intended. The results show that the subjectively perceived intensity of pressure and warmth was typically in agreement in all cuffs, in all conditions: the intensity of warmth follows that of pressure and is typically evaluated as being a little less intense. Evaluation of pleasantness regarding the sensations of pressure and warmth are also typically in agreement and are rated above neutral (at least slightly positive) for most conditions by all groups, with no significant differences.

In regard to the subjectively perceived intensity of warmth and pressure by each sleeve cuff, in the haptic conditions with sequential activation of the cuffs the first cuff, closer to the wrist, was on average perceived as producing the most intense pressure and warmth. In haptic conditions with sequential activation of the cuffs, participants on average perceived warmth and pressure intensity as being higher on the first cuff, gradually subsiding on the middle cuffs, and as increasing again on the fifth cuff, although not as much as in the first cuff. In haptic conditions of simultaneous activation of the cuffs, the intensity of the warmth and pressure in cuffs on the middle of the forearm was perceived as higher than that at the ends of the forearm. The results of perceived sensation combined show the patterns of haptic action significantly affect the perceived intensity of the sensations.

Affective Evaluation of the sleeve's haptic action. Results from the comparison of the absolute change from pre-testing assessment between the conditions that producing only pressure and conditions of the same haptic pattern that produced both pressure and warmth, demonstrate that the added warmth increases the impact of conditions. Results from the comparison of the absolute change from pre-testing assessment between the three groups demonstrate an important decrease in the feeling of being “Tired/Lethargic” in the Fast group and in the feeling of being “Excited/Enthusiastic” in the Slow group. When analyzing the results of absolute change from pre-testing assessment in regard to the affective dimensions, one can observe that the evaluations of opposite affective states belonging to the same affective dimension are typically complementary for the Slow and Fast groups but tend to be symmetric (of equal amount) in the Regular group, balancing each other out. This symmetry in the evaluation of opposite states by participants in the Regular groups suggests ambivalence or neutrality.

The results from the values that derive from subtraction of opposite moods, demonstrate increase in the negative values of the bipolar affective dimensions for the Slow group, and an increase of the positive values of the bipolar affective dimensions for the Regular and Fast groups. The results show that participants in the Slow group exhibited states of lower arousal than the participants in the Regular and Fast groups, and that participants of the Fast group exhibited states of higher arousal than participants in the Regular and Fast group. Comparing the affective spaces for each condition in the three groups on the radar charts, one can observe that the affective spaces in the Slow group tend to gravitate towards the bottom right quadrant of the Affective Circumplex. The affective spaces in the Regular group tend to gravitate towards the center of the Affective Circumplex. The affective spaces in the Fast group tend to gravitate towards the right semicircle of the Circumplex.

Overall, the results of the UI surveys demonstrate that the pace of haptic action correlates positively with the participants' arousal. The results also demonstrate associations with participants' valence: (1) pace of haptic action higher than participants' relaxed breathing rate promotes emotions of positive valence, including feelings of excitement; (2) pace of haptic action equal to participant's relaxed breathing rate has a minimal impact on participants' mood of slightly positive valence; (3) pace of haptic action lower than participants' relaxed relaxed breathing rate promotes feelings of slightly negative valence, including the feeling of tiredness, and feelings of positive valence, including the feeling of relaxation.

Interviews and Survey feedback. When asked about their experience wearing the sleeve, 66% of participants of the Regular group and 62% of the participants of the Fast group expressed a strong preference for either the conditions with simultaneous activation of the cuffs or the sequential activation of the cuffs. Only 38% of the participants in the Slow group expressed a strong preference for the simultaneous or sequential pattern of haptic action of the sleeve, possibly indicating the slow pace of haptic action smooths the differences between the different patterns of haptic action. Of all patterns of haptic action, the simultaneous pattern was the most controversial, being both the most favorable and most disliked among participants. Of the participants who preference the sequential pattern, most had preference for conditions 5 and 6 (half cycle activation) over 1 and 2 (full cycle activation).

Conditions 5 and 6 were often associated by participants with the feeling of having a soothing massage. Conditions 3 and 4 were often associated by participants with the activity of breathing: some reported a feeling similar to that of hugging a pet and feeling the pet breathing, or similar to feeling the breath of someone sleeping alongside them. Others reported that they felt that the haptic action in conditions 3 and 4 regulated their breathing. The breathing reference was often associated with calming affective states. A couple of participants who disliked the simultaneous pattern of haptic action (conditions 3 and 5) associated it with someone grabbing them or a with blood pressure cuff; the blood pressure cuff association was made mostly with the conditions that did not include warmth.

Many participants perceived the sequential conditions 5 and 6 as more natural than the sequential conditions 1 and 2. Conditions 1 and 2 were sometimes perceived as jumpy or anxiety provoking because they created anticipation of activation of the in-sequence cuff or because they required the wearer to focus more on the pressured forearm locations. Among participants, a few exceptions perceived conditions 1 and 2 as playful. The sequential activation including in conditions 1, 2, 5, 6 was sometimes compared to musical rhythms. When conditions 1 and 2 were compared to 5 and 6, the former were perceived as slower and the latter as faster. To some, the slower perceived pace of these conditions was calming whereas the faster energizing.

Regarding the perception of warmth and pressure, warmth was typically perceived as relaxing and the conditions combining both pressure and warmth more pleasant than those that contained only pressure. Participants' sensitivity towards sensations influenced the pleasantness of experienced sensations: participants typically disliked feeling the warmth or pressure being too intense. Aligned with the UI results, warmth and pressure were not perceived as being equally distributed along the forearm. Conditions with sequential haptic action were typically perceived as having more intense sensations at the first and last cuff and less intense at the middle cuffs. Conditions with simultaneous haptic action were perceived as being more intense in the cuffs on the middle of the sleeve and less intense at the ends of the sleeve.

Time seemed to be an important factor in the sensory and affective perception of the sleeve. Many participants reported that their experience changed within the duration of a haptic condition. For some, one or both of the sensations of warmth and pressure intensified during the haptic condition. Participants often felt conditions were more arousal provoking at the start, promoting excitement or anxiety, and more calming towards the end. The perception of sensations and affective impact of the sleeve was also reported as changing througout the study. In participants' subjective experience, the sensations often became more or less intense over time or were reported to cyclically change, increasing or decreasing in the middle. The affective impact also often changed during the study.

Some participants felt anxious at first but then became used to the sensation and eventually became more relaxed; others progressively felt more tired or anxious, while others had a more cyclical affective experience, starting out calmly, becoming anxious and then becoming calm again.

Apart from the duration of the study, the sequence in which the conditions were experienced probably also had an impact on participants' subjectively perceived sensations and affective feelings. The order of the conditions also possibly affected how condition 7 (control) was perceived, promoting in certain cases illusory feelings of pressure and or warmth. Condition 7 (control) was surprisingly reported by some participants as anxiety provoking due to the restlessness they felt waiting for sensations that did not arrive. This might be a good reason why based on EDA results participants demonstrate higher arousal levels on this condition than expected. Other conditions were also sometimes misperceived as having varying speeds, intensity or locations of produced sensations, perhaps due to the order of the conditions or other reasons.

Finally, participants on average perceived the study as pleasant, and some suggested more variety in the haptic action would be necessary to promote more intense or significantly different affective states. Participants typically were prone to wear the sleeve in their everyday life if they were users of similar devices or practitioners other sensory-based emotion regulation methods. Participants were sometimes eager to suggest other complimentary applications for the sleeve.

3.2.4.c. OVERALL CONCLUSIONS AND FUTURE DIRECTIONS

This study tested two hypotheses: the first was that the pace of haptic action of the sleeve is positively correlated with participants breathing rate, and negatively correlated with participants' perception of calmness. The results of the physiology data analysis, are aligned with my hypothesis as they demonstrate on average an increase in BR in the participants of the Fast group, and decrease in BR in the participants of the Slow and Regular groups, with the decrease being greater in the Slow group. Because of the wide data distribution, the results were not tested for statistical significance, yet they remain promising as they are aligned with the desired study direction.

The EDA results demonstrated that the most effective conditions in emotion regulation increase on average the wearer's arousal levels and cause higher decrease within the conditions. The EDA results also demonstrated a much higher change of EDA levels within conditions in the Fast group than the Slow and Regular groups, suggesting a stronger but more brief arousing impact of the fast-paced haptic action. The results of the Slow and Regular groups suggest a lighter but long-lasting calming impact of the slow-paced and regular-paced haptic action. Results from the interviews demonstrated that a perceived faster haptic action feels more energizing or anxiety provoking than a perceived slower haptic action, which feels more calming.

Results from the UI surveys and interviews also support the first hypothesis, as participants' evaluation in regard to the Affective Circumplex showed higher arousal levels in the Fast group than in the Slow and Regular groups and lower arousal levels in the Slow group than in the Regular group. The results showed that a fast pace of haptic action promoted emotions of positive valence, including feelings of excitement, and not negative feelings of anxiety, as initially expected. The slow pace of haptic action promoted emotions of slightly negative valence, including feelings of tiredness; it also promoted feelings of positive valence, including feelings of relaxation. The regular pace of haptic action had a minimal positive impact.

The second hypothesis that was tested in this study was that distinct haptic conditions correspond to distinct affect states. For the hypothesis to be proved, we would ideally expect each haptic condition to lead to a different distinct affective evaluation. This was not the case. However, important distinctions can be made regarding some of the parameters of the conditions. Some conditions felt more natural (conditions 3, 4, 5, 6) than others (conditions 1, 2) and were typically perceived as more pleasant and less distracting. The feeling of the haptic action as being unnatural was perceived either as negative and anxiety provoking or as playful. Preferences over sequential and continuous pattern of haptic action were polarized among participants (conditions 1, 2, 5, 6 versus conditions 3, 4) with some regarding one pattern as positive and calming and the other as energizing or anxiety provoking.

In regard to the second hypothesis, conditions including both pressure and warmth were perceived as more pleasant by the majority of participants than haptic conditions including only pressure, regardless of the pattern of haptic action. The sensation of warmth was perceived as calming by the majority of participants. Although it should be noted that the sensation of warmth was never produced alone, without pressure. In future studies, it is worth testing haptic action solely with warmth in comparison to haptic action solely with pressure. The perception of warmth and pressure differed according to the pattern of haptic actions: in sequential patterns the first and last cuff in sequence was always perceived as causing more intense sensations, whereas in simultaneous patterns, the middle cuffs were perceived as causing more intense sensations. Through participants' testimonies, it became apparent that conditions were perceived as ordered and similar, and that more variety between the conditions could lead to more distinct and diverse affective responses.

Interesting questions arose regarding the impact of time within the haptic conditions, as well as regarding the accumulative impact of the haptic conditions' testing time throughout the study. In future studies testing haptic conditions for longer periods of time, it is worth exploring further if sensory response reaches a peak and then subsides and whether this pattern differs based on the pace of haptic actions. Physiological results of this study indicated such a possibility, but further studies would be needed to arrive at conclusions. The results of the oral reports in the interview also suggest further investigation on the impact of time, as both the affective perception and sensory perception of the haptic action of the sleeve seemed to be affected by time.

A mystery of this study, remains the response to condition 7 (control), as the results were unexpected. EDA and BR analysis results are surprising in that they show similar response in condition 7 compared to the rest of the conditions. Based on the interviews, we understand that the inactivity of the sleeve caused restlessness and anxiety, and this may be one of the reasons why condition 7 did not prove to be a good control condition. Another conclusion from the interviews is that there was an after-effect based on previously experienced sensations, which could be either a physiological residue or a phycological illusion. A future study with more participants and perhaps a different design to incorporate a control condition less affected by the rest of the conditions (perhaps as a different group, or as a condition with no sleeve at all) could shed more light on the mystery.

Finally, in the discussion of the results of the first study [chapter 3.1], I posed the question whether the impact of the sleeve is subliminal, due to conscious activity or synchronization of the body to the sleeve's action. Because the sensations in the second study were much more intense than the barely perceptible sensations in Study I, it is difficult to arrive at conclusions regarding a possible subliminal effect of the sleeve. We can only conclude that participants were in general aware of the sensations with the exceptions of several misperceptions and placebo effects. Awareness of the sensations does not necessary mean that participants breathing was consciously regulated. A different, future study would be needed to evaluate this factor.

4. Affective Matter - Connect

An interface for material-mediated emotion regulation and communication, and reflections on mediated social touch

4.1. INTRODUCTION AND SCOPE

Affective Matter suggests a method for both intrapersonal and interpersonal affective communication through the synchronization of programmable material environments and our bodily functions. Studies I and II [chapter 3.1-3.2] demonstrated the effectiveness of this method for intrapersonal communication in two controlled studies using a programmable affective sleeve. In this chapter I first review the current field of mediated social touch and its limitations and discuss what aspects of the studies I conducted can be considered as contributions to this field. I then reflect on future potential studies on mediated social touch via Affective Matter. Finally, I proceed to the main focus of this chapter which is the design and development of the Affective Matter - Connect user interface. The interface addresses both material-mediated interpersonal and intrapersonal communication and can be useful in future applications of the affective sleeves either for the purpose of self-regulation or for the purpose of remote haptic communication of affect.

My initial intention was to develop an interface that would enable me to do a controlled study on interpersonal material-mediated affective communication. However, the Covid-19 pandemic prevented me from conducting in-person studies. Because of restrictions on educational facilities and limitations imposed by COUHES —the committee that acts as the Institutional Review Board (IRB) at MIT— only an online controlled study would have been permitted, which presented many additional technical challenges exceeding the timeline limitations on this dissertation.

Ironically, the Covid-19 pandemic -- which was an obstacle in my research, preventing me from completing the studies as initially planned — made the work of this dissertation more relevant. During the pandemic crisis, tactile exploration became a viral threat, forcing us to withdraw from the richness of the world of touch and from our usual tactile language of communication. As discussed in the early chapters of this dissertation, touch is important for fostering interpersonal bonding in both social and intimate relationships. Touching another individual changes the sense of self, dissolving boundaries. Touch also promotes interpersonal bonding by allowing the interpersonal synchrony that occurs when one feels the bodily rhythms of another [see chapters 2.1.3; 2.1.5].

Material-mediated interpersonal communication via Affective Matter could add the missing tactile connection in remote communication by allowing wearers of a pair of affective sleeves or other programmable wearable material environments to exchange affective information through haptic means. Moreover, Affective Matter could expand of the bandwidth of our affective communication, allowing the transmission of physiological aspects of emotions via materials. One may ask, why reveal to others what is normally hidden in our bodies? As discussed in the first chapters of this dissertation, communicating emotions through language is often a challenge. Physiological aspects of emotions give direct information about an emotional state that is not interpreted through language and/or labeled according to cultural norms.

Beyond the informational role of Affective Matter in interpersonal communication, Affective Matter could potentially contribute to interpersonal emotion regulation. Emotion regulation in interpersonal relations occurs on many occasions in our everyday lives. For example, when we are upset or sad, we might talk to a good friend or family member, who may choose the appropriate words to soothe us and show empathy. The soothing words of this trusted person will likely comfort us, reducing anxiety and increasing levels of calmness. A different kind of regulation can take place when we visit a mental health counselor or psychotherapist, who, usually using verbal advice or cognitive behavior methods, aims to help us regulate our affective states. The emotion regulation that takes place in those interpersonal relations can be enhanced through Affective Matter in non-verbal, purely sensorial means, potentially complementing existing therapeutic, and social support methods.

4.2. MEDIATED SOCIAL TOUCH AND THE CONTRIBUTIONS OF AFFECTIVE MATTER

A significant number of researchers have proposed methods or devices for remote haptic communication or remote haptic affective communication [see Smith and MacLean, 2007; Van Erp and Toet, 2015; Haans and Jsselsteijn, 2006 for a review]. Not taking into account haptic communication systems for the blind or visually impaired that stem back to the invention of the Braille system in 1824,[1] haptic interfaces have been explored since the 1960's. Gerald [1960] was one of the first to discuss the possibilities of non-verbal communication using vibrotactile stimuli. Recent research on non-verbal remote communication has also explored a variety of patterns of vibrotactile stimuli produced by tangible devices. For example, Chang et al., [2002] envisioned ComTouch, a device used as an add-on to a mobile phone that translates finger pressure into vibration. Similarly, Reed at al. (2019) utilized a variety of phonemic-based vibrotactile patterns on a wearable sleeve, translating spoken language into a tactile code.

Beyond systems that aim at codifying spoken language and meanings into haptic means, many systems have been developed targeting haptic social interaction. Haans and Ijsselsteïjn [2006] define as mediated social touch "the ability of one actor to touch another actor over a distance by means of tactile or kinesthetic feedback technology." The earliest examples of mediated social touch were made for entertainment purposes. One such example is the Electronic arm wrestling system developed by White and Back in 1986.[2] The system enabled two individuals to wrestle remotely by connecting two robot arms in a telephone line system. A great amount of research on haptic interfaces and mediated haptic social interaction is currently focused on virtual reality and entertainment applications, including vibrotactile or pneumatic vests [Delazio et al., 2018; Arafsh et al., 2012] and vibrotactile haptic suits such as the Teslasuit by Tesla.[3]

A relevant to my approach research is that conducted by Huisman and colleagues [2013] who utilized sleeves for interpersonal communication in haptic means. The sleeves use vibrotactile and not pneumatic (or other

---

1 https://brailleworks.com/braille-resources/history-of-braille/

2 The project was presented at the Arts Initiative Symposium, in Salerno, Italy. See the artist's page for more information: http://www.normill.ca/artpage.html. Accessed 10/4/2021

3 https://teslasuit.io/ Accessed 10/13/2021

form of squeeze type) stimulation. The haptic response to the receiver is defined through haptic input by the sender (touch of the sender's sleeve is translated into a vibrotactile pattern into the receiver's sleeve). A similar tactile device for communication currently on the market, in the form of a wristband, is Punchcut.[1] Various haptic patterns (of force, vibration, and temperature) are associated with distinct emotions. Unlike the haptic communication via Affective Matter I propose, the mentioned approaches are neither based on physiology studies to determine affective association nor utilize physiological measurements of the wearers for the haptic communication. Another research on a vibrotactile sleeve on affective communication, without testing the connection to physiology measures, was conducted by Zhang et al. (2020) who tested how visual stimuli on a sleeve may enhance the impact of the vibrotactile stimuli.

Devices for mediated haptic social interaction have also been developed with the aim to reduce social anxiety in interpersonal interactions and/or promote calmness through the tangible presence of the other. Sumioka et al. showed that the stress-reducing effect of interpersonal touch can be achieved through huggable objects in remote interpersonal communication [Sumioka et al, 2017]. In a later study, Sumioka et al., [2021] showed that the use of huggable pillows in phone communication can reduce social anxiety in individuals on the autism spectrum. Mueller et al [2005] developed an inflatable vest that can be remotely activated to resemble a hug, and Bonanni et al., [2006] discussed therapeutic wearable haptic systems with the ability to record and play back human touch. A variety of other systems have also been developed to enrich remote communication between partners through haptic means, including the representation of haptic events such handholding, pats, squeezes, massages [see Van Erp and Toet, 2015 for a review].

In addition to the aforementioned developed systems, some of the haptic wearables and devices made for virtual reality experiences also aim at enhancing the users' affective experience. For example, Emojacket implements affective haptic patterns applied in various locations of the upper body [Arafsh et al, 2012]. Although there is big production in the design of systems for remote affective haptic communication, research that dives deeper into the evaluation of the aspects of emotions that can be communicated through haptic means is scarce [see Erp and Toet, 2015 for a review]. Examples (briefly described below) are limited in number and focus on basic forms of simulated touch such as force feedback or vibration.

The study by Smith and MacLean [2006], was one of the first recent studies to evaluate communication of affect through a haptic link in

1 https://punchcut.com/immersion/ Accessed 12/16/2021

a structured, designed study. Smith and MacLean utilized a simple pair of knobs allowing for vibrotactile feedback between a pair of participants and a set of more elaborate virtual models that acted as metaphors for mediated communication. In the study they showed that participants were able to communicate a set of specific emotions correctly most of the times. In the same analytical direction, Salminen et al., [2008] utilized a small device that produces patterns of rotational continuous and discontinuous haptic stimuli on the finger, evaluating those patterns in terms of the three dimensions of perceived arousal, valence, and dominance. The study concluded that discontinuous stimuli were perceived as pleasant and approachable and less arousing and dominating than continuous stimuli.

Unlike Smith and MacLean [2006], Salminen et al., did not study the perception of haptic stimuli in the communication between study participants, but studied individual affective responses. The evaluation of the haptic stimuli in affective terms, even if focused on individual responses, indirectly contributes to the study of mediated affective communication as it helps evaluate the types of stimuli to be used in potential communication applications. Another study that indirectly (i.e. without the use of an explicit communication system or method) contributes to mediated affective communication is the study by Tsalamlal et al. [2014]. Using an air jet based tactile simulation, Tsalamlal et al, conducted an experiment asking for the subjective affective evaluation of different types of tactile sensations through air pressure in terms of the arousal, valence, and dominance dimension. They concluded that different aspects of emotions can be communicated by varying the intensity of the air flow.

Precedents in the field of affective haptic communication often focus on the development of devices or proposed haptic patterns without accompanied evaluation studies. Both reviewers and researchers of the field [Erp and Toet, 2015; Salminen et al., 2008] highlight the scarcity in the affective evaluation of haptic stimuli that can be used in communication applications. The conducted studies on Affective Matter [Study I and II] contribute to the field of mediated affective haptic communication as they demonstrate affective reactions to specific haptic stimuli produced by the affective sleeves. The combined study results demonstrate that haptic stimuli along the forearm including pressure and warmth are typically perceived as more pleasant and calming than haptic stimuli along the forearm including only pressure. They also demonstrate that slow-paced haptic stimuli along the forearm are more calming than fast-paced haptic stimuli along the forearm that are more arousing. Finally, Study II also demonstrates different affective perceptions regarding simultaneous and sequential stimuli, as these are discussed in the respective chapter.

The studies I conduced are the first to examine the affective response to the specific patterns of haptic stimuli along the forearm. In addition, the levels of skin conductance, and the change of breathing rate included in the studies I conducted, are important indications of one's affective state. To my knowledge, more analytic studies on the affective response to haptic stimuli, including the ones discussed earlier, are limited to subjective evaluations lacking validation from a psychophysiological perspective. Based on the results of Studies I and II, one could potentially use a fast-paced haptic action to communicate a affective state of high arousal, such as an excited or stressed state, and a slow-paced haptic action to communicate an affective state of low-arousal such as a peaceful or calm state.

The studies particularly contribute to the subfield of mediated affective research that focuses on a sensory-based affective interpretation of haptic stimuli rather than a cognitive-based (symbolic) affective interpretation of haptic stimuli. A cognitive-based interpretation addresses how affective states can be expressed as specific haptic stimuli (e.g. “hapticons” as the haptic equivalent of emoticons) [Rovers, et al. 2004; Enriquez and MacLean, 2003]. A sensory-based affective interpretation addresses the feelings produced by specific haptic stimuli, which is the case of the studies I conducted as well as the studies reviewed earlier [Salminen et al., 2008; Tsalamlal et al. 2014]. The boundaries between these two lines of investigation (cognitive and sensory based) are not clearly distinguished in the literature, although there is an obvious distinction between the two kinds of research. The distinction is highlighted by a few researchers of the field, albeit not using the exact terminology I used [Salminen et al, 2008, Erp and Toet, 2015].

Relevant literature focusing on emotional responses to haptic stimulation is sometimes referring to materials as “eliciting” rather than “communicating” emotions [Suk et al. 2009; Erp and Toet, 2015]. It is important to note that research on how haptic stimuli may elicit certain emotions adds a new dimension to research on mediated social touch and mediated affective communication. Similar to the claims I made in this dissertation, Erp and Toet [2015] anticipate this new research dimension by remarking that “interpreting communicated emotions differs from eliciting emotions as the former may be considered as a cognitive task not resulting in physiological responses, e.g., one can perceive a touch as communicating anger without feeling angry.” Pointing to relevant embodied theories of emotion, the researchers also note that “the existence of specific neurophysiological channels for affective touch and pain and the direct physiological reactions to touch indicate that there may be a direct link between tactile stimulation, physiological responses, and emotional experiences” Erp and Toet [2015]

It is to that, potentially new, physiological dimension of mediated social touch that I wish to contribute through further research on intrapersonal mediated communication via Affective Matter. I hypothesize -- a hypothesis to be tested in future research -- that haptic stimulation provided to wearer A, based on physiological signals of the connected via Affective Matter wearer B, can provide information to wearer A about aspects of emotions that wearer B is actually feeling (and not merely an affective message they wish to communicate).

The results of the studies I conducted suggest that haptic stimulation may elicit certain affective states or modulate certain affective states. A future study with two participants communicating through the affective sleeve could provide evidence regarding one's affective response to information of another's physiological state. Although such a study was unfortunately not conducted due to covid-19 restrictions, the studies described in earlier chapters and the interface that will be described in this chapter, lay the foundations of such future research.

The conducted studies on Affective Matter have also extended the field of exploration of affective responses to haptic stimuli. Most research in the field, perhaps due to ease of implementation to existing communication interfaces, have focused on communication potentials of vibrotactile stimuli, and only to a lesser extent to pressure related (squeeze) and thermal stimuli. Studies that explore users' reaction to different kinds of haptic and tactile stimuli are scarce [Suhonen et al., 2012], and utilize subjective ratings only rather than a combination of subjective ratings and physiological measurements. Although vibrotactile stimuli may be easier to implement in existing types of interfaces, haptic stimuli that combine thermal and pressure (squeeze) stimuli, simulate better the feeling of human touch and thus may potentially have a stronger impact on mediated social touch.

The studies I conducted provide a basic haptic repertoire that could be evaluated further in a setup of mediated social touch. For example, light to medium intensity warmth and/or pressure was most often evaluated as pleasant and more intense warmth and/or pressure as unpleasant. A fast pace of pressure and/or warmth along the forearm was most often perceived as arousing and a slow pace as calming. Those stimuli and their affective associations can be put into test in an interpersonal setup to investigate whether they can help convey aspects of relevant affective states. Studies on social relationships have already shown that different temperatures can elicit different affective perceptions and reactions [Ijerman and Semin, 2009].

An important aspect of social touch is its role in increasing empathy. As reviewed in the second chapter of this dissertation, a significant amount of theories and studies support the hypothesis that interpersonal touch increases social bonding. In addition, as also reviewed in the second chapter, recent scientific studies demonstrate that interpersonal synchrony, in terms of motor activity and/or physiology may occur in the process of understanding another or empathizing with another. A hypothesis I intended to test, but remains to be tested in the future, is whether mediated affective communication through Affective Matter can promote empathy by causing certain physiological activities of the connected individuals' to synchronize. Evidence in this direction pertaining to direct physical touch (and not mediated touch), has been shown by Chatel-Goldman et al. [2014].

The impact of mediated affective communication on interpersonal synchrony can only be shown if a study with pairs of participants is conducted in the future. However the fact studies I and II indicated that the wearable material's rhythmic action possibly synchronized with (or at least impacted the rhythm of) the wearers breathing activity, suggests that autonomic coupling through mediated haptic affective communication might be possible. Thus, the results of the studies, combined with research on physical direct touch [Chatel-Goldman et al., 2014], hint at possibilities of mediated touch via Affective Matter to promote interpersonal synchrony.

Research on mediated affective communication focuses either on "mutually agreed" haptic symbols that could be used to express a certain affective state [Rovers, et al. 2004; Enriquez and MacLean, 2003] or "commonly felt" physiological/emotional reactions to haptic stimuli [Suk et al. 2009]. In other words, it is typically assumed that a common haptic language of communication can be established through haptic representations with intersubjective meaning or intersubjective psychophysiological reactions to haptic stimuli. My goal in the following sections of this chapter will be to highlight another important aspect of mediated affective communication that is not typically addressed in the existing literature: the customization possibilities of a haptic language in order to reflect individual affect response and affective meanings.

Even if the studies I conducted suggested that certain haptic parameters are tied to common psychophysiological reactions (e.g. fast pace to high arousal, and slow pace to low arousal), the same studies suggested that reactions to other parameters may significantly vary for each individual. In the following chapter sections, through the description of Affective-Matter Connect UI, I demonstrate a design and computational method for mapping physiological signals to personalized haptic action. The interface takes into account some basic physiologically derived intersubjective mappings (e.g. the breathing rate is an indication of high or low arousal), combines them with the subjective affective evaluations, and is personalized by the user.

4.3. AFFECTIVE MATTER - CONNECT INTERFACE

4.3.1. LESSONS LEARNED FROM STUDIES I & II

One of the goals of Study II was to conduct research towards building a repertoire of haptic sensations that can be used for material-mediated interpersonal affective communication. Although the haptic conditions chosen for the study had a slightly different impact on participants' psychophysiology, results demonstrated that there was no one-to-one mapping of haptic conditions to affective states. However, the results of Study II did lead to important conclusions regarding parameters of the haptic action. Those parameters were taken into account when considering what a haptic affective repertoire would comprise and how the architecture of the User Interface could facilitate building and customizing such repertoire.

One conclusion drawn from Study II was that conditions with a faster pace of haptic action were more arousing than conditions with a slower pace of haptic action. This was true for conditions following a full breathing cycle and for conditions following a half breathing cycle. The comparison between the group wearing a sleeve with a slow pace and the group wearing a sleeve with a fast pace of haptic action demonstrated that the slow pace promoted feelings of calmness and tiredness, whereas the fast pace promoted feelings of excitement and high energy. Because the pace of haptic action of a wearable material environment has an impact on the wearers' psychophysiology, I concluded that the parameter of the pace of haptic action needs to be taken into account when designing a system for affective communication.

Another parameter that I observed as having an important effect on participants' affective state was the sensation of warmth. The majority of participants in Study II experienced the sensation of warmth as soothing and comforting, contributing to feelings of calmness. There were also exceptions to this rule, as warmth for some participants caused more unease than comfort. Study II made it apparent that although there is an overall tendency for people to perceive warmth as calming, warmth's intensity can promote feelings of anxiety and discomfort. Similarly, the perception of pressure intensity varied among forearm location and among participants, although in general participants felt greater sensitivity near the wrist. Thus, adjustment of the pressure sensation needs also to be taken into account when considering customization of haptic parameters in the User Interface.

Predictability of rhythm, intensity and direction of the haptic action were also parameters discussed by participants of Study II as affecting their affective experience. In haptic patterns that felt more natural (such as the sensation of breathing), predictability was in general a positive factor, whereas when the haptic patterns were not perceived as natural, predictability often contributed to annoyance. Unpredictability of the parameters of the haptic action was also a parameter contributing to high arousal, interpreted by some as anxiety and others as excitement. Some of the participants of Study II discussed possible anxiety-provoking haptic conditions as having variability in direction and intention. Other participants argued that variety in the parameters would result in more excitement and engagement. Thus the direction of haptic action and the degree of its randomness should also be parameters to consider as being customizable in the User Interface.

Studies I and II demonstrated that often the natural or cultural links participants made to the sleeve had an impact on how they perceived the sleeve's haptic action. For example, associations of the sleeve with a blood pressure cuff often had a negative impact on how participants perceived the sleeve. Associations of the sleeve with living beings, either humans or animals, were usually positive, as they evoked feelings of the close company of another, although sometimes they evoked feelings of being aggressively touched or grabbed by another. Cultural or natural associations inevitably affect one's affective perception of a physical sensation. To take into account varied cultural contexts as well as possible associations made at a personal, psychological level, I thought that the maximization of user customization parameters would be necessary.

The challenge in interpersonal affective communication is to account for the associations made by each individual. For example, if a certain pattern of haptic action reminds person A of the feeling of holding a furry cat and that association makes them calm, person B, who is connected remotely through Affective Matter to person A, may not necessarily make the same association; perhaps person B associates the sensation not with a furry cat but with a stranger's hairy hand, a thought that may be anxiety provoking; or perhaps person B makes the furry cat association, but is allergic to cats and so becomes anxious instead of calm; or perhaps person B simply does not like warmth around their arm because it makes them sweat. The possibilities of association and affective interpretation are endless. Thus a communicated affective message needs to be decoded based on each individual's repertoire of associations and personal sensitivities.

4.3.2. COMPUTATIONAL DESIGN PRINCIPLES

As I discussed earlier, affective communication is not always about how we actually feel. In everyday communication we often exchange affective messages with positive or negative content either verbally or by text – for example, a positive message of an upcoming celebratory event, or a negative message of cancelled celebratory event. Although such messages have positive and negative content respectively, they do not necessarily affect our moods. Thus, one of goals in the design of the interface was to distinguish between communicating a person's affective state or mood (how they actually feel), and sending an affective message -- a message that carries a certain valence, that can be culturally evaluated as positive or negative, that does not necessarily convey how the sender actually feels.

In order to design the User Interface I first defined certain design computation principles for material-mediated communication and regulation that address the following: (1) how one's affective state would be "labeled" — from what kind of data the system would infer one's affective state, and what kind of algorithm it would apply for such inference; (2) how information regarding one's affective state would be communicated to another individual, meaning — how the information would be coded into material behavior to be received by the connected individual; (3) the possible directions of affective information — whether communication would be one-way or two-way, and how information would be transferred through one material channel during bidirectional communication; and (4) the types of exchanged information — affective messages or information regarding one's mood.

The User Interface was designed to allow the following: (1) Connection to one wearable material environment (e.g., programmable affective sleeve) per user; (2) Real time integration of physiology data from sensors; (3) Collection of user qualitative data and integration with the quantitative data to determine an affective state; (4) Handling of more than one kind of affective information (i.e., sending an affective message vs. directly communicating one's feelings); (5) Customization of the intensity and pattern of produced sensations; (6) Customized mapping of the wearable environment's produced sensations to affective evaluations; (7) Ease of use, positive experience, and scalability — exploring a design that could be implemented in various devices (smartwatch, phone, pc). Not all listed parameters are currently implemented or fully implemented.

Material-mediated affective communication is based on the assumption that two or more individuals are remotely connected via Affected Matter. For simplicity, we can assume that each individual is wearing an affective sleeve of the kind developed for Study II, and each individual is also wearing biosensors to measure breathing rate and skin conductance levels. We also assume that the individuals have access to the UI, for example, through their smartphones. It is important to note that we could imagine individuals wearing a different pair of wearable material environments, such as a pair of vests, pants or suits, gloves, or huggable pillows. A pair of individuals could also wear different paired objects; for example, one could be wearing a vest, and the other a sleeve, as information could be decoded differently for each individual and wearable object.

Affective communication and regulation via Affective Matter utilizes the Affective Circumplex as its basic reference for mapping affective information into affective states but opens up the system to more nuance interpretation by requiring evaluation of both the positive and negative spectrums in an affective dimension similar to methods used in study II. Results from Studies I and II indicate that the data from physiological measurements are good indicators of one's arousal state but not so good indicators of one's valence state. In the context of a controlled experiment, we can assume that the high arousal state is related to the experimental context. However outside the controlled conditions of an experiment, it is almost impossible determine the cause of arousal levels; the person could be stressed (negatively aroused) or enthusiastic (positively aroused).

For the above reasons, I decided that the physiological measurements from the biosensors should determine the values of the Arousal dimension of the Circumplex only. The values of the biosensors are not used to determine the Valence state of the individual as this can vary based on context, which, if not in a controlled study, is unknown. I decided that the values of the valence dimensions should instead be determined by the individual's subjective user input. Studies I and II provided evidence in two directions that support this decision: (1) Participants of studies I and II revealed information regarding the valence dimension of their feelings through subjective evaluation; (2) During Study II changes in the valence dimension were not as significant as in the arousal dimensions. Extrapolating from Study II, user feedback regarding valence provided several during the day might suffice to determine the values of the valence dimension of one's overall mood. One could of course increase the frequency of user input for more accurate results, or the user can decide to update the input when they feel they need to do so.

In short, in the User Interface, the values of the Arousal axis of the Circumplex are determined by physiological measurements, and the values of the Valence axis are determined by users' subjective input [FIG III. 1]. In the current state of the interface, only the breathing rate activity is used to determine the valence levels, but measurements of more physiological functions could be used and compared to determine the results. Regarding the user's subjective input, in future steps of the implementation the user will be required to provide input regarding their valence in programmed intervals (at least once a day or every couple of hours) through the User Interface. Other ways of providing user feedback could possibly be implemented in the future through user action directly on the material environment instead of a digital interface.

Types of Affective Communication. In a setup where two or more individuals are connected via Affective Matter, communication can occur in a variety of ways depending on how the affective signals are transmitted from one individual to the other [FIG III. 2]. The kinds of communication that can take place via Affective Matter are the following:

> ***One-way communication (Affective Monitoring).*** In this type of communication, at least one individual is a sender of affective information, and at least one is a receiver of affective information. Physiological signals (and subjective input) from the sender are transmitted through Affective Matter to the receiver by being coded into values of arousal and valence, and then decoded into a form of haptic action to be received by the receiver. One-way communication can be used for monitoring --for example when monitoring someone's anxiety crises in the event that the individual cannot monitor themselves due to developmental or other disabilities.
>
> ***Two-way asynchronous communication (Affective Exchange).*** In this type of communication, all individuals communicating are both senders and receivers of affective information, which alternates in direction. At any given moment in any affective material channel of communication, there is one direction of information, meaning that an individual is either sending or receiving affective information to another connected, via Affective Matter, individual. Physiological signals (and subjective input) from the sender are transmitted through Affective Matter to the sender by being coded into values of arousal and valence, and then decoded into a form of haptic action to be received by the receiver. This type of communication takes the form of a dialog; affective information is sent in response to received affective information.
>
> This type of communication can be used in interpersonal relations with friends or loved ones in lieu of text messaging or as a way of feeling each other's presence. This type of communication can also be used in a mental health context, as non-verbal affective information exchange to facilitate the treatment of non-verbal

individuals, individuals with developmental disorders or simply individuals that find it hard to put their feelings into words.

Two-way synchronous communication (Affective Synchronization). In this type of communication, two individuals communicating are both senders and receivers of affective information but information is sent concurrently in both directions. At any given moment in any affective material channel of communication, there are two directions of information; an individual is at the same time sending and receiving affective information from another connected individual. Physiological signals (and subjective input) from the sender are transmitted through Affective Matter to the sender by being coded into values of arousal and valence, then decoded into a form of haptic action to be received by the receiver.

In this type of communication between individuals A and B, at any given moment, A feels through haptic action certain aspects of the affective state of B (physiological aspects mostly but also informed by the A's self-reported valence as it will be described in the next section), and B feels through haptic action certain aspects of the

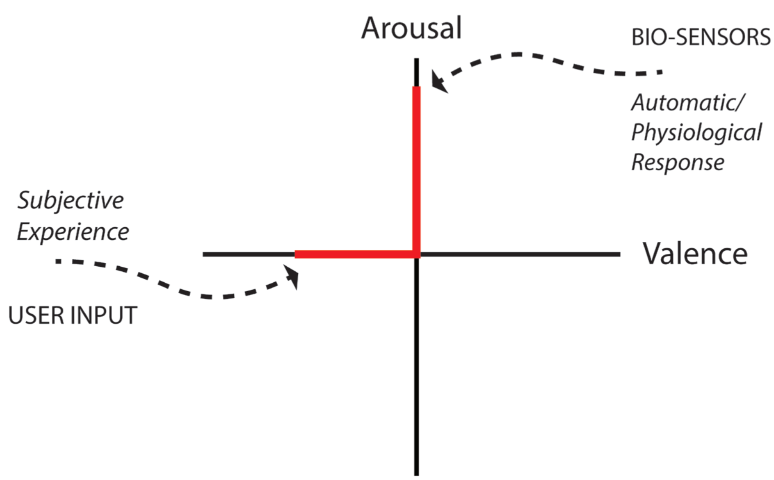
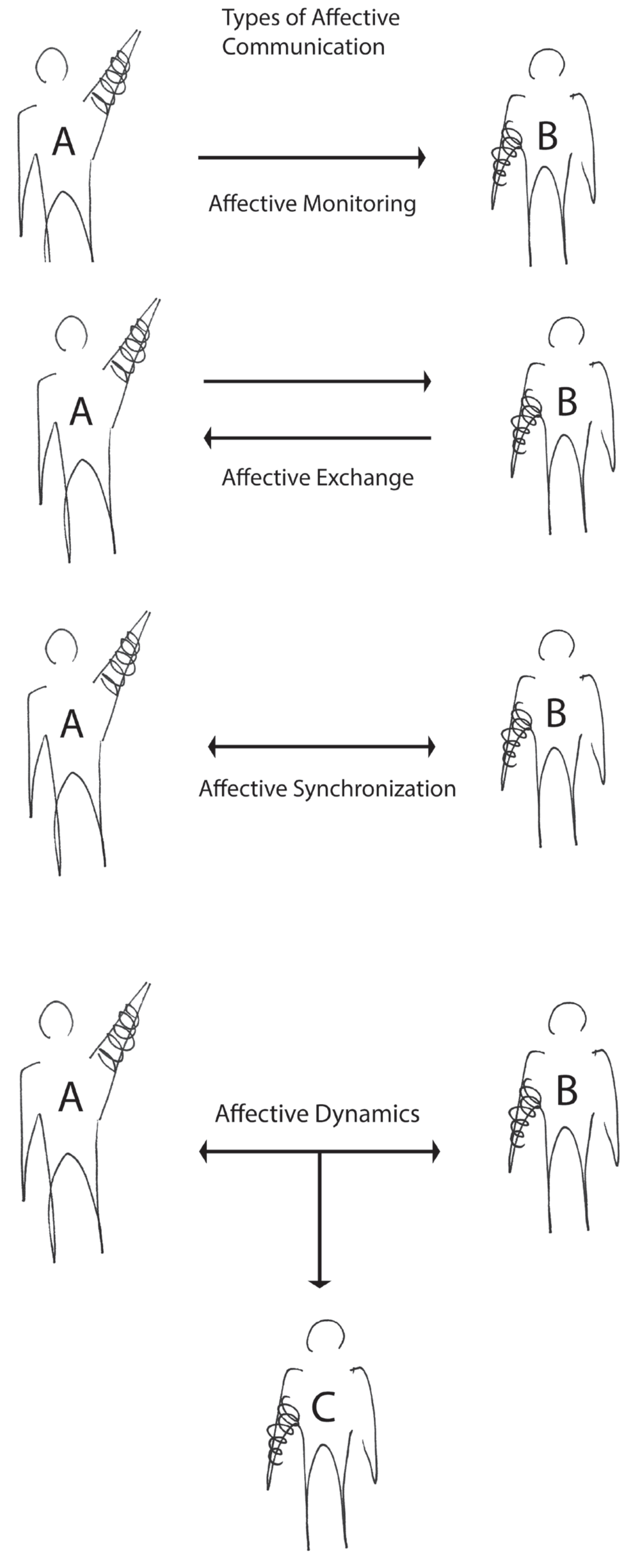


FIG III. 1
In the Affective Matter - Connect User Interface, the values of the Arousal axis of the Circumplex are determined by physiological measurements, and the values of the Valence axis are determined by users' subjective input

FIG III. 2
Types of affective communication enabled by the Affective Matter - Connect User Interface



affective state of A. This type of communication takes the form of an interpersonal and synchronous affective dance. This type of communication can be used in interpersonal relations with friends by promoting empathy, or it can be used in a mental health context for the purpose of emotion regulation. This type of communication applies to no more than two individuals at a given time, as what one individual feels is translated into the haptic action of the other individual's sleeve.

Collective Communication (Affective Dynamics). In this type of communication, two or more individuals communicating are both senders and receivers of affective information, but the information is averaged into a collective affective state which is transmitted to all connected individuals. At any given moment, an individual can both send and receive affective information from other connected individuals. Physiological signals (and subjective input) from all senders are transmitted through Affective Matter to all receivers by being coded into values of arousal and valence, averaged into a collective state, and then decoded into a form of haptic action to be received by the receivers. This type of communication expresses collective affective dynamics.

Types of Affective Information. In affective communication, we need to distinguish between the kinds of affective information that can be transmitted. In the context of the UI design I make the distinction between information pertaining to one's Affective State and information pertaining to an Emotion event. In the context of the interface one's affective state is equivalent to their arousal and valence levels as these are defined from the physiology sensors and user feedback respectively.

In the context of the Interface an Emotion Event is defined as an event including an emotional reaction that can be externally or internally generated. It might simply be a thought that triggers a reaction, or it may be an event generated in our environment, such as a comment another has made or news that we have just learned. The Emotion event is also defined through its valence and arousal parameters but also has the added parameter of time, as emotion events are of specific duration. Sending information regarding sender's affective state and sending information regarding an emotion event can both change the receivers affective state. However it was my intention to not address affective change in the UI. It would very challenging to try to address all the contextual (cultural, personality-related) parameters that can affect how one will react to affective information. A simplified approach to modeling affective change would likely fail to address the complexity of human behavior.

4.3.3 DESIGN AND DEVELOPMENT

4.3.3a. EARLY DESIGN EXPLORATION

The Affective Matter interface was designed to address both emotion self-regulation and interpersonal affective communication via Affective Matter. I focused my initial exploration on the possible features that could be included in the interface. Would the interface allow for affective communication via the haptic modality only, or would it allow communication via haptic and other modalities? Our everyday remote communication with others relies heavily on texting and video chatting; Affective Matter could offer an additional modality that would expand the bandwidth of our existing affective communication, allowing us to communicate remotely through audio, text, video and touch. Affective Matter could offer the additional haptic modality that is missing from our remote affective communication. We would be able to see a friend on a video chat, hear their voice, write to them via messaging app, and touch them via the affective sleeve or other affective wearable environment.

In Affective Matter research discussed so far, I have used the Affective Circumplex as the underlying framework for the evaluation and categorization of affective states -- even though I made the important modification of including evaluations for multiple dimensions. I thus decided that the Circumplex should be one of the basic components of the interface. Based on the Affective Circumplex, I developed an Affective Wheel as an interactive component that would allow the user to see their mood status, make selections regarding their desired affective changes, and use it as the platform to create and send affective messages (emotion events). In my initial designs of the interface, I created mockups of different graphic interpretations of the Affective Wheel along with different versions of how a multimodal affective interface would integrate remote haptic communication with text, video, or voice, or all of those communication modalities together [FIG III. 3].

An initial idea I had regarding an interface integrating text and remote haptic communication included a window for text-chatting and an Affective Wheel with different colors defining an affective state. In this version of the interface, the users would be able to “assign” an affective state to the texts they are exchanging in the chat window. The assignment would be possible through tactile interaction, by touching the section of the wheel with the relevant affective state and then subsequently creating a new text message. Based on the color assigned to each message -- each message being a distinct “text bubble” in the chatting window -- the sleeve (or other wearable environment) would provide the corresponding type of haptic action. If this version of the interface were to be further

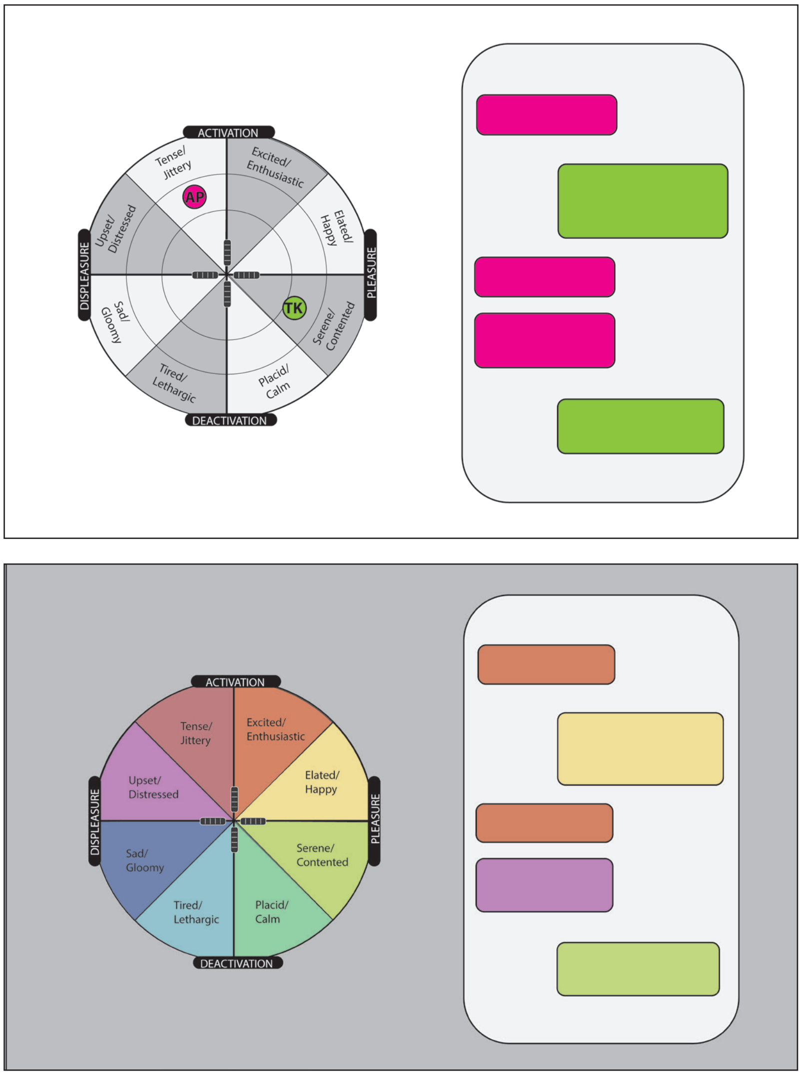


FIG III. 3
Early versions of the Affective Matter - Connect interface exploring the integration of text messages along with the Affective Wheel.

FIG III. 4
Early version of the Affective Matter - Connect interface exploring the integration of video communication along with the Affective Wheel. Photo source: Shutterstock

developed, one would have to resolve how to address the duration of the haptic action corresponding to each text bubble and how to make it coincide with the action of reading the text message [FIG III. 10a].

Another early version of the interface explored the integration of video communication along with remote haptic communication via Affective Matter [FIG III. 4]. In this version, the user can see on one side of the screen the Affective Wheel, and on the other side the video window. The two connected individuals can see each other on the Video application, and also see each other's location on their Affective Wheel based on their current affective state. The users would be at the same time connected through the affective sleeves (or other wearable environments) exchanging information regarding their moods {FIG III. 11a]. A slightly different version of the interface integrates both a video and text chatting application; users could take advantage of all communication modalities while using the Affective Wheel to determine the affective context of the message that will be translated into haptic action. Finally, I explored what these versions would look like if the communication involved more than two people.

After exploring various possibilities for combining different modalities in communication, I decided that the final version of the interface would include only remote haptic communication via Affective Matter. I made this decision because I wanted to fully explore the potentials of the new haptic material modality of communicating affect and because —to facilitate use and scalability— I wanted to keep the interface as simple as possible. In addition, I thought that some of the benefits of remote haptic communication might not be available if other communication modalities were also integrated into the system. As mentioned earlier, remote haptic communication via Affective Matter could possibly be less distracting than text messaging; a person wearing an affective sleeve could type on their laptop or do physical exercise while at the same time receiving affective messages through the sleeve's haptic action.

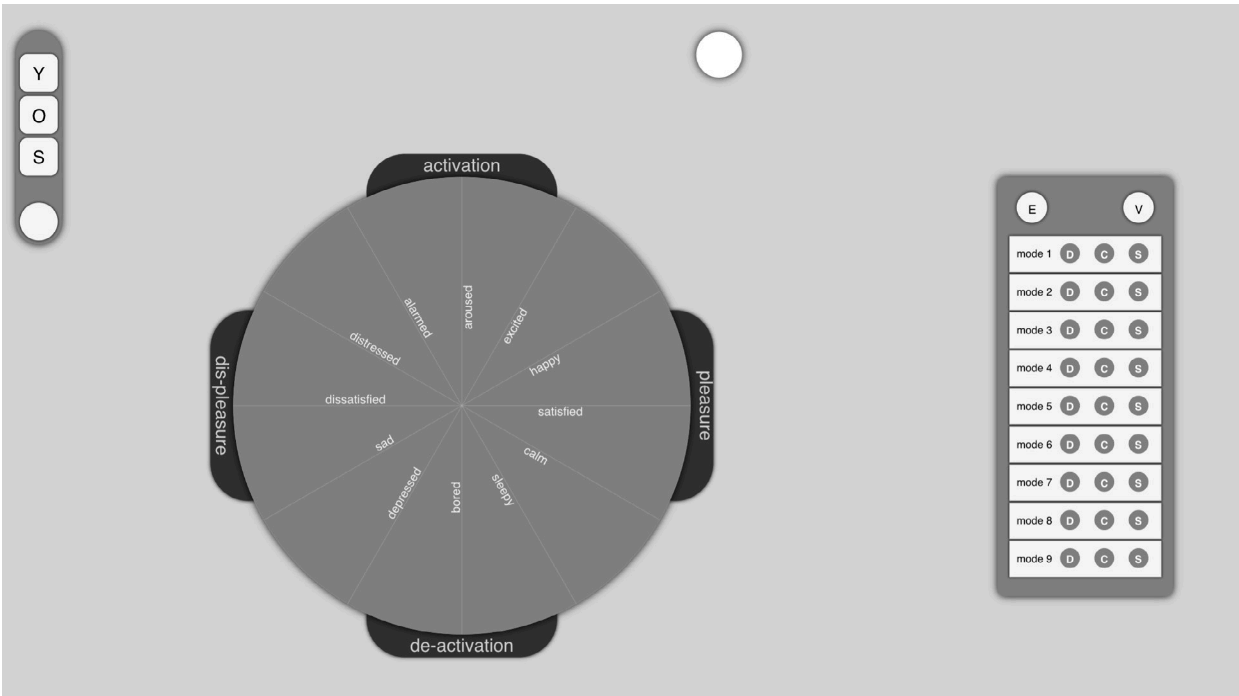


FIG III. 5
Affective Matter - Connect UI: *Setup* page

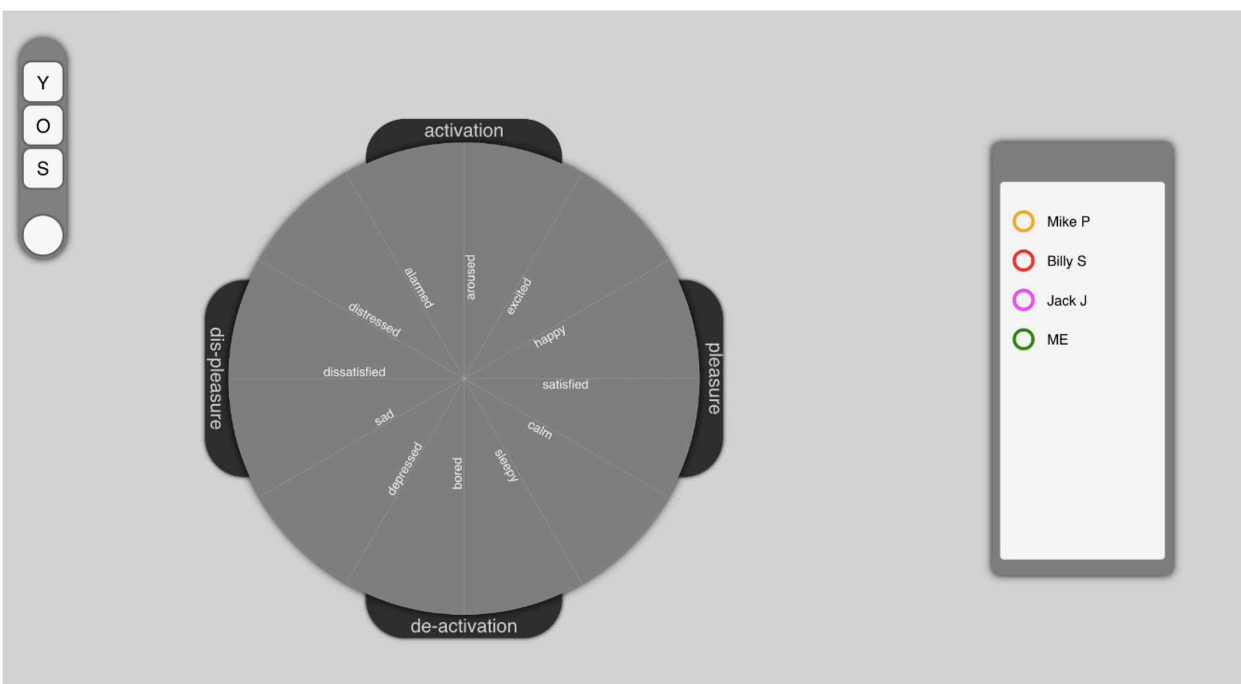


FIG III. 6
Affective Matter - Connect UI: *Connect-To-Others* page

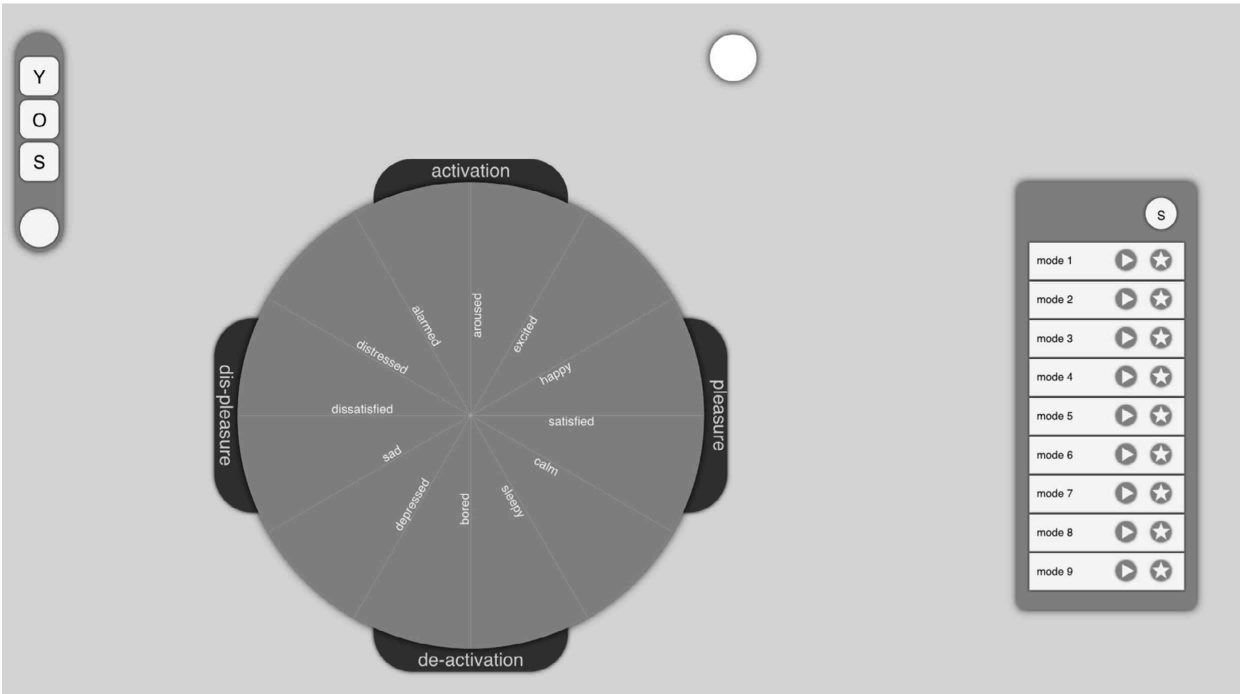


FIG III. 7
Affective Matter - Connect UI: *Connect-To-Yourself* page

4.3.3b. FINAL DESIGN AND IMPLEMENTATION

The final version of the Affective Matter interface includes three directories that can operate independently or together. The first directory addresses the setup of the sleeve (or other wearable material environment); the second directory addresses emotion self-regulation; the third addresses interpersonal affective communication [FIG III. 5-7]. The reason why these three functions are bundled together is because a user can benefit from both self-regulation and communication features with one wearable material environment, as both functions rely on haptic action. Since the material and hardware needed are the same for both regulation and communication usage, one can benefit from using the same digital application and server to store the user's data. In addition, since customization would be needed for both the regulation and communication options, having one setup directory for both facilitates usage.

As discussed in earlier sections of this dissertation, emotion self-regulation via Affective Matter is also a mode of communication -- intrapersonal material-mediated communication. Thus the Affective Matter interface is thought of as a "connection" platform: one can choose to connect to one's own self or to others. Under this general intrapersonal/ interpersonal connection concept, I designed the interface as beginning from a main page with a menu that allows the user to choose between three options: "Setup," which directs to the setup page; "Connect to Yourself, " which directs to the self-regulation page; and "Connect to Others," which directs to the interpersonal communication page. The same menu appears on all three pages, allowing easy navigation between all the features of the Affective Matter Interface. Information that has been submitted on one of the three pages is accessible from all three pages, which are connected to the same server.

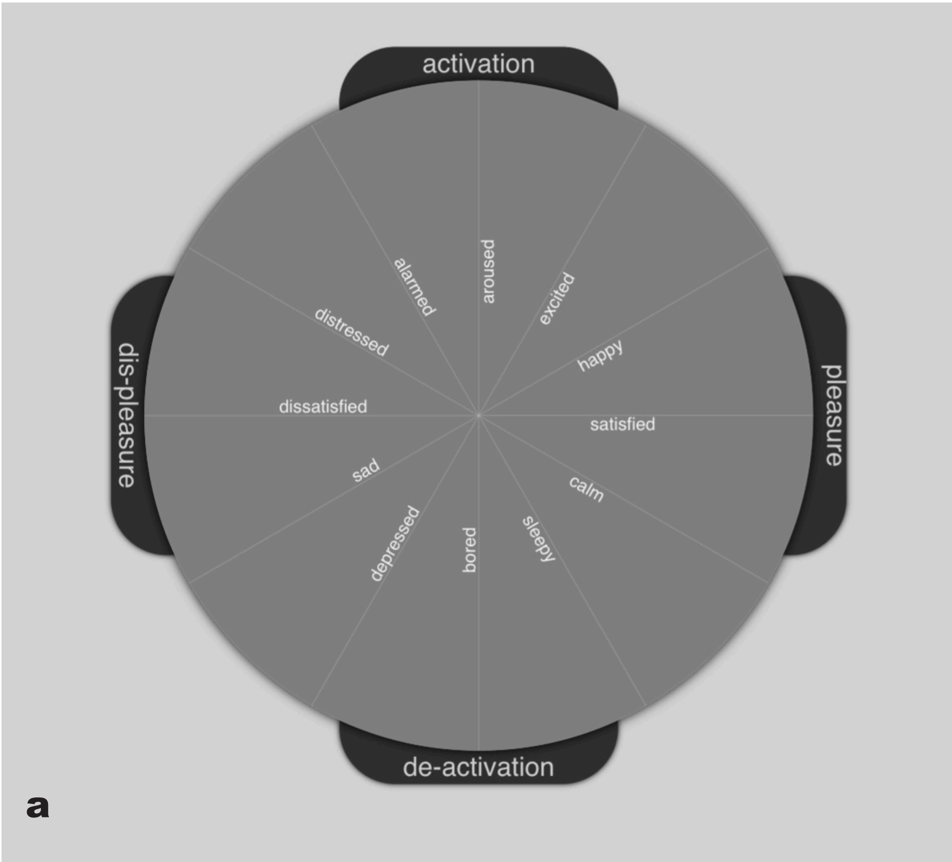
The three pages (Setup; Connect to Yourself; Connect to Others) are designed based on common principles so that the user can smoothly switch from one to the other. There are two main components on the page: the Wheel, which switches between an Affective Wheel and a Haptic Wheel, and the Panel, which switches between a Contacts Panel and a Modes Panel. The Affective Wheel is designed following the Affective Circumplex model. In Study II, the Circumplex was divided into 4 axes of opposite pairs of affective states, resulting in 6 different affective states. In the Affective Matter interface, I decided to use 6 dividing axes, resulting in 12 distinct affective states. Unlike Study II, in which a pair of names denoting similar affective states was used to label each state, in the interface only one name denotes the state in each subdivision of the Affective Wheel [FIG III. 8].

The decision to add more subdividing axes to the Circumplex is related to the user experience and the granularity in the evaluation of one's subjective state. In Study II, because users evaluated their affective states using sliders creating a longer list of affective states would not be efficient. In the Affective Matter - Connect interface, the evaluation can be done directly on the Affective Wheel, which allows the user to use the mouse to hover over the different affective states and mouse-click to choose the appropriate state. This component of user interaction makes the selection of states faster and more efficient. The other reason for increasing the number of subdivisions of the Circumplex was that I wanted to offer the users the possibility for a more refined evaluation of the affective qualities of their sleeve (or other wearable material environment) [FIG III. 8].

The Modes Panel is placed on the side of the screen and is used to allow adjustment of the haptic parameters of the sleeve (or other wearable environment) in the Setup and Connect to Yourself pages, and to allow the user to connect to other users in the Connect to Others page. The Wheel is the most prominent feature of the interface, and the part that needs to be visible on the screen. Such an interface can be adjusted to fit various devices and screens. Even on a smartphone one could comfortably see the Wheel on the screen and use touch-screen interaction to choose a desired affective state. In addition to the Wheel and the Panel, the three pages include an additional menu component that allows switching between them. The precise concept, design, and user experiences each page provides are described in detail bellow:

Setup. General Features. The purpose of the Setup page is to allow customization of the sleeve or other wearable material environment. Customization can be done on two levels. The first level concerns the material sensations produced by the sleeve; the second concerns the affective evaluation of the produced sensations. Based on the results of Study I and II, I decided that it was equally important to address both levels of customization. In this manner, the sleeve (or other wearable material environment) could exactly conform to the wearer's individual preferences and sensitivities. For consistency and simplicity of the design, I decided to adapt the evaluation of the haptic parameters of the sleeve to an interactive radar chart evaluation -- the Haptic Wheel -- so that the evaluation and visualization of the haptic qualities would be similar in shape and style to the evaluation of the affective qualities.

On the Setup page, the user has the option to switch between the Affective mode and Haptic mode with the click of a button at the panel. Switching to Haptic mode switches the wheel from the Affective Wheel to the Haptic Wheel, which includes physical parameters of the haptic sensations; it also switches the mode of the panel to address the material



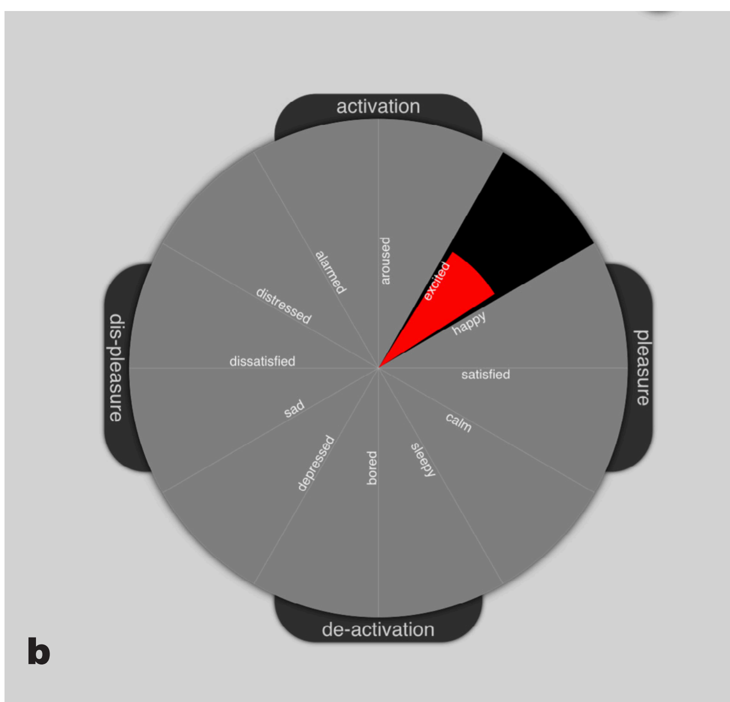
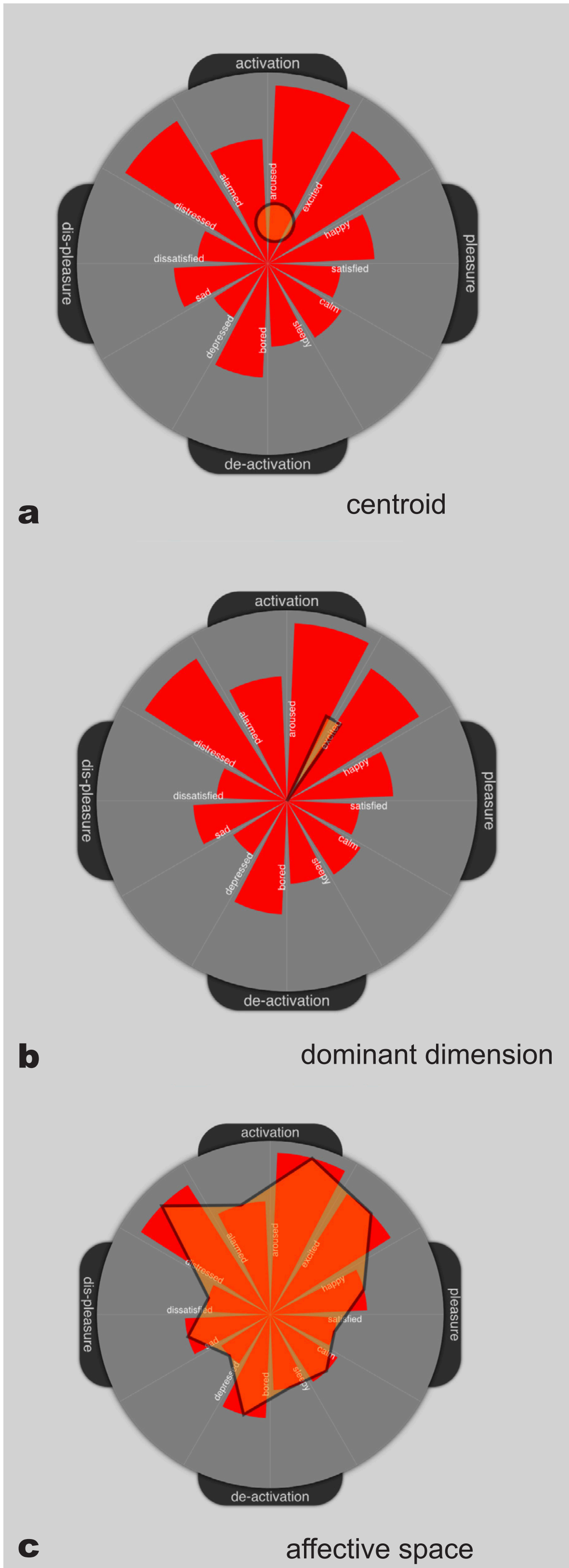


FIG III. 8
(a)The Affective Wheel consists of the following 12 sectors each corresponding to an affective state in order starting clockwise from 12 o'clock: "aroused," "excited," "happy," "satisfied," "calm," "sleepy," "bored," "depressed," "sad," "dissatisfied," "distressed," "alarmed"
(b) The user can click on each circle sector to modify the value (felt intensity) of the affective state: upon mouse-click on the circle sector, a second circle sector in red color appears on the screen whose diameter increases and decreases based on the user's mouse location.

FIG III. 9
The View Setting allows the user to see salient features of each of the set haptic modes and compare them: (a) the centroid; (b) the dominant dimension; (c) the affective space reflecting the intensity of the 12 affective states of the 6 affective dimensions.



haptic parameters. The Haptic Wheel is identical in size and shape to the Affective Wheel but does not include anything equivalent to the main axes of arousal and valence which are displayed along with the Affective Wheel. In the Affective mode the labels “Pleasure” and “Displeasure” are displayed behind the Affective Wheel at the right and left end of the valence axis, respectively, and the labels “Activation” and “Deactivation” are displayed at the top and bottom of the arousal axis, respectively. The labels are used to make the evaluation more intuitive when the wheel is set on the Affective mode.

Setup. Affective Mode. In the Affective Mode, the Affective Wheel appears on the screen. The Affective Wheel consists of the following 12 sectors each corresponding to an affective state in order starting clockwise from 12 o’clock: “aroused,” “excited,” “happy,” “satisfied,” “calm,” “sleepy,” “bored,” “depressed,” “sad,” “dissatisfied,” “distressed,” “alarmed” [FIG III. 8a]. I chose these labels after reflecting on categorizations suggested in previous literature on the Affective Circumplex. Although one could choose from a variety of alternatives to label a certain area of the Circumplex -- for example, for the middle upper-right quadrant one can choose between the similar affective states of “enthusiastic,” “excited,” “ebullient,” “vivacious,” “fervent, ” among others -- I wanted to utilize the names of affective states that are commonly used in English and understood by everyone. When considering different affective states as label choices for the Affective Wheel, my intention was to pick affective states that would much their opposite, at the other end of the respective axis.

The 12 affective states form the following six axes of opposite states: “aroused-bored,” “excited-depressed,” “happy-sad,” “satisfied-dissatisfied,” “calm-distressed,” sleepy-alarmed,” and “bored-aroused.” When the user hovers the mouse over the Affective Wheel, the circle sectors corresponding to each affective state turn from grey color to black, denoting the affective state that can potentially be selected. The user can then click on the circle sector to modify the value of the affective state: upon mouse-click on the circle sector, a second circle sector in red color appears on the screen whose diameter increases and decreases based on the user's mouse location. By another mouse-click, the diameter of the red circle sector becomes fixed, setting the value of the affective state [FIG III. 8b]. The same procedure can be followed for all other affective states, and the values can be set and reset as needed. In addition, a reset button, located on the top right of the Affective Wheel, can reset all states at once, facilitating editing [FIG III. 5].

In the context of the Affective Matter interface, the values of the affective states are meaningful when set in response to specific stimuli or parameters. On the Modes Panel at the right of the Affective Wheel the user has access to preset haptic modes. Each haptic mode includes a set of haptic sensory stimuli that the wearable material environment is programmed to produce for the purpose of material-mediated intrapersonal or interpersonal communication. The user can select which haptic mode they wish to experience through their wearable material environment by pressing a specified button and can stop the sensory experience pressing the same button. The idea of having a list of haptic modes that the user can choose to experience is inspired by popular music applications. Like moving through a playlist of songs, the user can pick a desired haptic mode to experience through the sleeve or other wearable material environment.

On the Setup page, the Modes Panel has two settings: the View Setting and the Setup Setting. The Setup setting allows the user to both play a haptic mode and edit a haptic mode; it also allows the user to see the set values of a haptic mode. To play a haptic mode, the user clicks on the play/stop button; to edit a haptic mode, the user uses the record button, which records the values that are set at the Affective Wheel at that moment. The user then can view the values using the view (star) button. The user can then edit again the set values for a specific haptic mode by either clicking the view button to show all values and then selectively clicking on the affective state they wish to modify, or by determining new values from scratch. Once the user has the new desired values, the values can be recorded again using the record button. To facilitate use and switching from one haptic mode to another, each haptic mode has its own set of buttons.

The View Setting of the Modes panel switches the buttons of the panel while showing again the list of haptic modes. The View Setting allows the user to see salient features of each of the set haptic modes and compare them. The user can see the dominant affective dimension of a haptic mode, the centroid of a haptic mode, and the affective space of a haptic Mode, through three corresponding buttons (‘D,’ ‘C’, ’S’) [FIG III. 9 a-c]. The dominant affective dimension is calculated by comparing the values of all affective states, as these have been assigned by the user, to find the one of highest value. Then from the affective state of highest value, the value of the opposite state of the same dimension is subtracted. The remaining value determines the value of the dominant affective dimension, depicted as a narrow circle sector on top of the corresponding dimension. The affective space is defined by creating a polygon whose vertices are the middle points of the arcs of the sectors defining the intensity value of each affective state. The centroid is the centroid of the points forming the vertices of the affective space. Through the Modes panel the user can compare various Modes by viewing their salient features concurrently on the Affective Wheel [FIG III. 10-11]

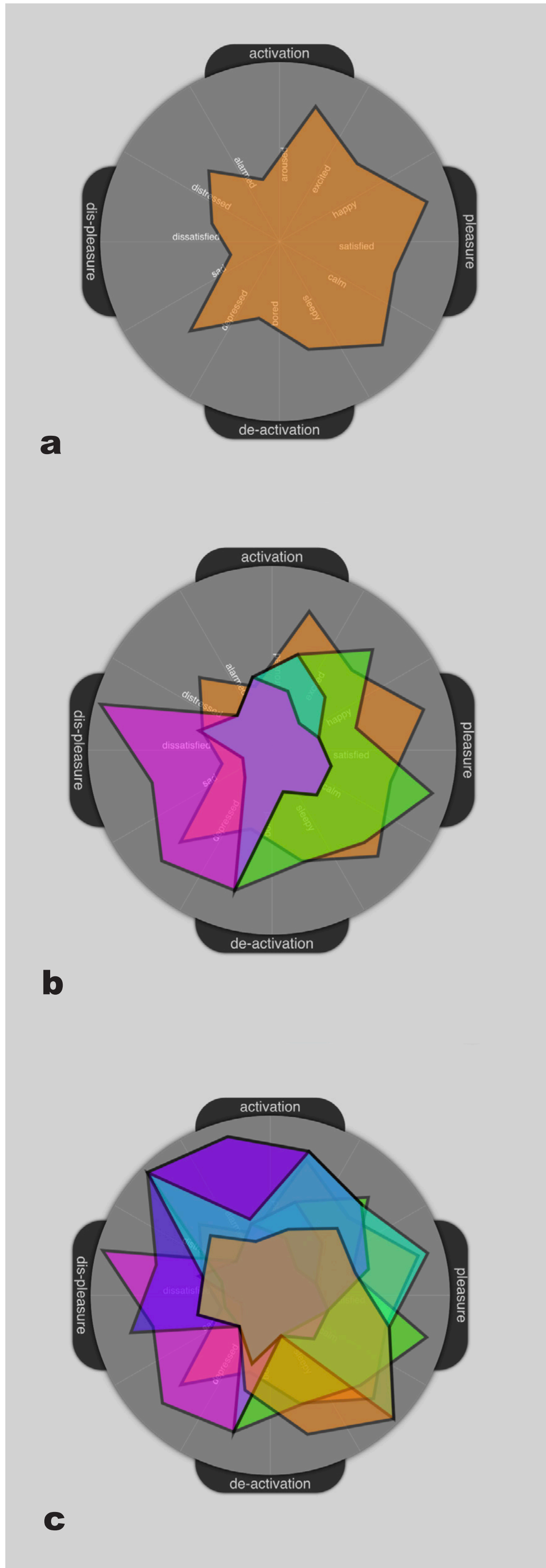
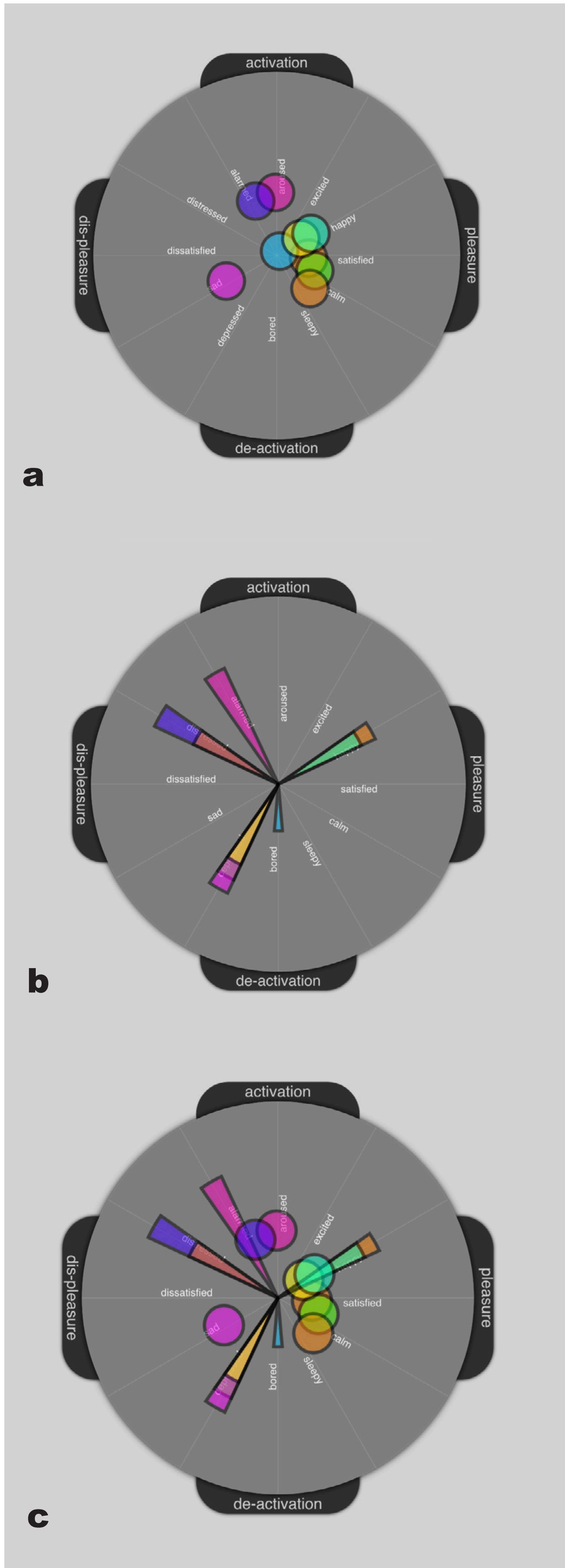


FIG III. 10
Using the Modes panel the user can compare various Modes by viewing their salient features concurrently on the Affective Wheel: (a) the affective space of a haptic mode; (b-c) Overlay of affective spaces corresponding to distinct haptic modes

FIG III. 11
Using the Modes panel the user can compare various Modes by viewing their salient features concurrently on the Affective Wheel: (a) Centroids of distinct haptic modes; (b) Dominant dimensions of distinct haptic modes; (c) Overlay of centroid and dominant dimensions of distinct haptic modes



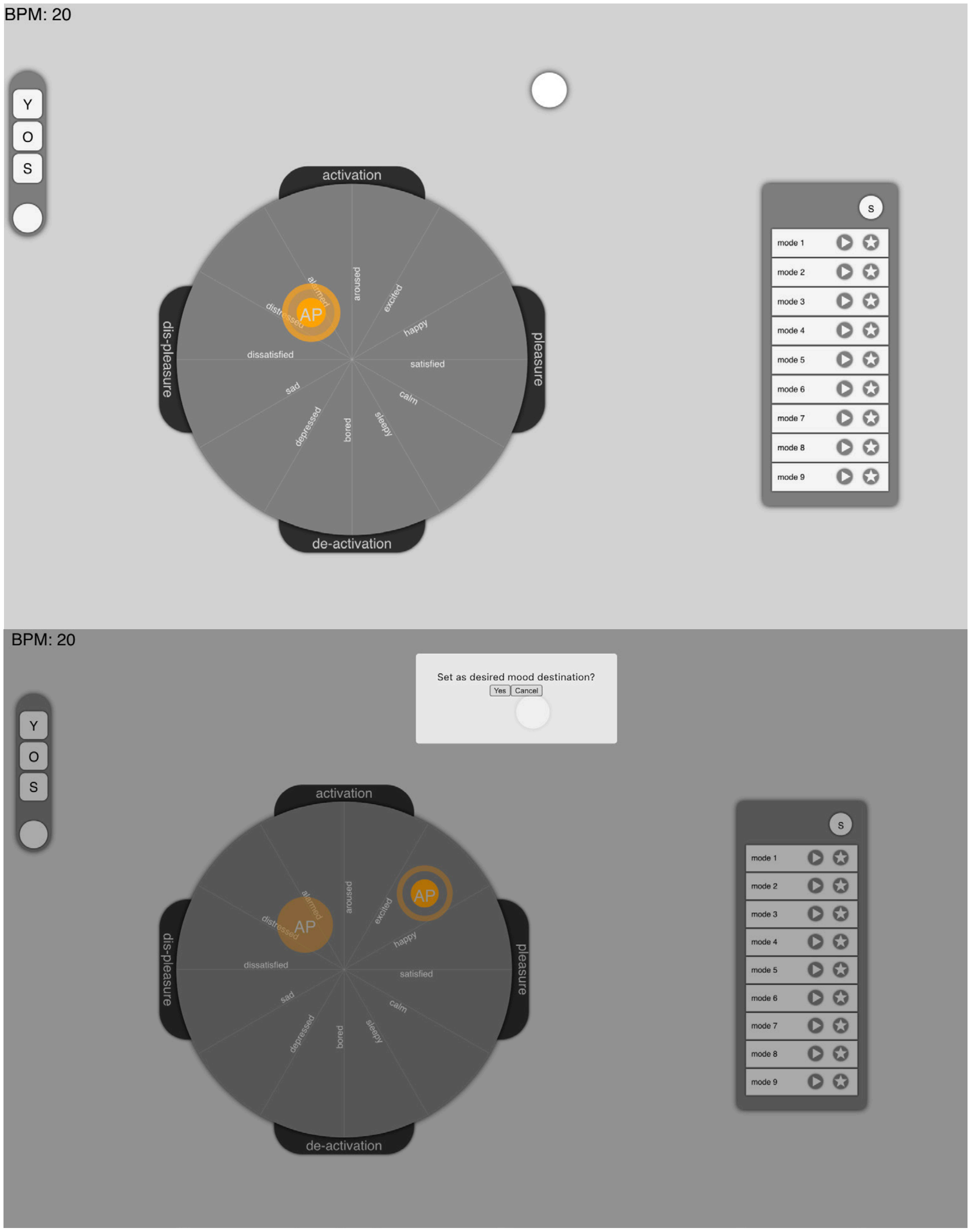


FIG III. 12
In the Connect to Yourself page the user can view their affective state on the Affective Wheel (top) and also set a Target Mood (bottom). Based on the selected Target Mood the UI can provide a list of haptic modes to experience based on the user's customized preferences and settings. In the current state of the implementation the suggested modes are calculated based on the distance between the Target Mood and the centroids of the evaluated haptic modes.

Setup. Haptic Mode. In the Haptic Mode, the Haptic Wheel can have as many divisions (sectors) as needed for the parameters of the wearable material environment. For example, for an affective sleeve like the one used in Study II, the user could evaluate the following parameters: number of cuffs to be used, activation cycle, heat intensity, direction, and speed. Not all these parameters can be adjusted in a linear manner; some need to be a choice between certain fixed categories -- for example, a direction can be either upward, downward, mixed or random. For now, all parameters have been visualized as having a simple setting controlled by the user in a same linear manner. For each parameter of the wearable material environment to be evaluated, there is a corresponding sector in the Haptic Wheel that the user can click on and then adjust. Similar to the Affective Wheel, a sector will change color when the user hovers the mouse over it, and upon mouse-click an additional sector will appear on the wheel whose diameter follows the mouse location and whose value becomes fixed upon second mouse click.

In the Haptic Mode, the Modes panel also has two settings: the Setup Setting and the View Setting. In the Setup Setting, the user sees the full list of haptic modes and can choose to experience them through the play button. The user can also choose to edit the physical parameters (heat, pressure, and so on) of each haptic mode through the Haptic Wheel. The view (star) button allows the user to view the values on the wheel, adjust them through the interactive Haptic Wheel, and record new values through the record button. The user can re-edit the values as many times as they wish or reset them using the reset button at the upper right of the Haptic Wheel. The View Setting of the Modes Panel functions similarly to the Modes Panel in the Affective Mode in that it allows the user to see salient features of the haptic Modes and compare them. The Modes Panel in the Haptic Mode includes a haptic space feature where the user can see the polygon created by all haptic parameters mapped on the Haptic Wheel for each haptic mode.

Connect to Yourself. The Connect to Yourself page allows the user to regulate their Mood through material-mediated intrapersonal communication (emotion self-regulation). The Connect to Yourself page consists of the same Affective Wheel and Modes Panel as in the Setup page except that the user is not allowed to modify the haptic modes (to modify the user needs to switch to the setup page). The user can choose to regulate their mood by defining a Target Mood on the Affective Wheel: at any given moment, the user can see a circle located at the position of their current affective state. Through a drag-and-drop feature, the user then has the option to drag the circle representing their current affective state to a desired location. Once the circle representing the current affective state is dragged, a new circle appears that represents the Target Mood. Once the circle is placed on the new location, a confirmation dialog window appears on screen with the prompt: “Set as desired mood destination?” If the user confirms, the Target Mood is set [FIG III.12].

The current affective state is calculated as follows: Real-time measurements from the physiology sensor are received by the server the interface is connected to. The measurement can be sent from a connected breathing sensor, heart activity sensor, skin conductance sensor, or other biosensor. In its current implementation, the interface receives real-time measurements from the E-sense Mindfield respiration sensor. The signals are received real-time by the server, which then uses an algorithm I implemented to calculate the breath per minute and maps it on the arousal dimension of the Circumplex (the Affective Wheel).
To determine the location of the current affective state in addition to the arousal level value, a valence level value is needed. The valence level value is provided through user input in the UI as mood input in set intervals of time (every couple of hours).

The following actions are designed to be implemented in the future in the Connect-to-Yourself page: Based on the user’s current affective state and the Target Mood an algorithm calculates which of the available haptic modes are most suitable for the user to experience (and for how long) in order for the user to arrive to their desired Target Mood. The calculation is based on proximity of the Target Mood to the centroids of each Haptic mode as defined in the Setup page. In the Modes panel the haptic Modes appear in order matching to the algorithm’s recommendation. The idea for haptic mode recommendations is similar to the way music applications makes song recommendations based on one’s mood. The difference between the Affective Matter interface and the music applications is that --beyond of course the fact that a haptic sensation is offered instead of auditory one— in the Affective Matter interface recommendations are calculated based on information from biosensors and one’s subjective input. If the user prefers a fully self-directed operation, they have the option to set the sleeve’s haptic action directly to their own prefer settings and activate/deactivate the haptic action at any time. In that case the user can simply select a haptic Mode from the list, which would be programmed based on the their preferences, set in the setup page.

Connect to Others. The Connect to Others page is the page where the user controls the material-mediated interpersonal communication with others. The page consists of the Affective Wheel and the Contact Panel. In the Contact Panel the user sees a list of all available contacts they can connect with, similar to a social media platform, and chooses with whom to connect and whether they’d like to connect in a two-way or a one-way communication mode. The user can also choose to send to one or more of their contacts an emotion event and control its intensity [FIG III. 13-19].

On the Affective Wheel the user always sees their current affective state depicted as an affective circle with their initials. Once the user clicks on any of the available contacts on the Contact Panel, an affective circle of distinct color appears next to the Affective Wheel with the initials of that contact the user can potentially connect with. If the user clicks again on a contact on the Contact Panel the affective circle with the contact's initials is being removed. The user can choose to connect with that active contact by clicking on both the contact's affective circle and their own affective circle. The interface allows both unidirectional and bidirectional connections provided that the connected users permit the type of connection.

Once two users of the Affective Matter interface are connected, they can receive information regarding each other's affective state. For example, in a synchronous two-way communication between A and B, both wearing an affective sleeve, B will feel a haptic action corresponding to aspects of A's current affective state, and A will feel a haptic action corresponding to aspects of B's current affective state. Because both A and B have the chance to customize the physical and affective parameters of their affective sleeves, what they feel is the aspects of the affective state of the other person mapped onto their own affective vocabulary. For example, if B is anxious and B perceives warmth as anxiety-provoking but pressure as soothing, and A perceives pressure as anxiety-provoking and warmth as soothing, A will receive haptic action with pressure and not warmth, as the feeling is mapped to each person's preferences set in the Setup page of the interface.[1]

In addition to the one-way or two-way mood information exchange between users, a user can send an Emotion Event to one or more connected users. Unlike affective information regarding one's affective state, an emotion event has a short duration. The users should understand the affective meaning of the emotion event in the same way, but the haptic action the event produces may differ for each user according to personalized settings. In its current implementation, the event sends a message of specific arousal and valence based on the user's affective evaluations of haptic modes on the Setup Page. Upon double clicking, a ring appears on the location representing the event and its intensity. The user can choose to increase or decrease the intensity of

---

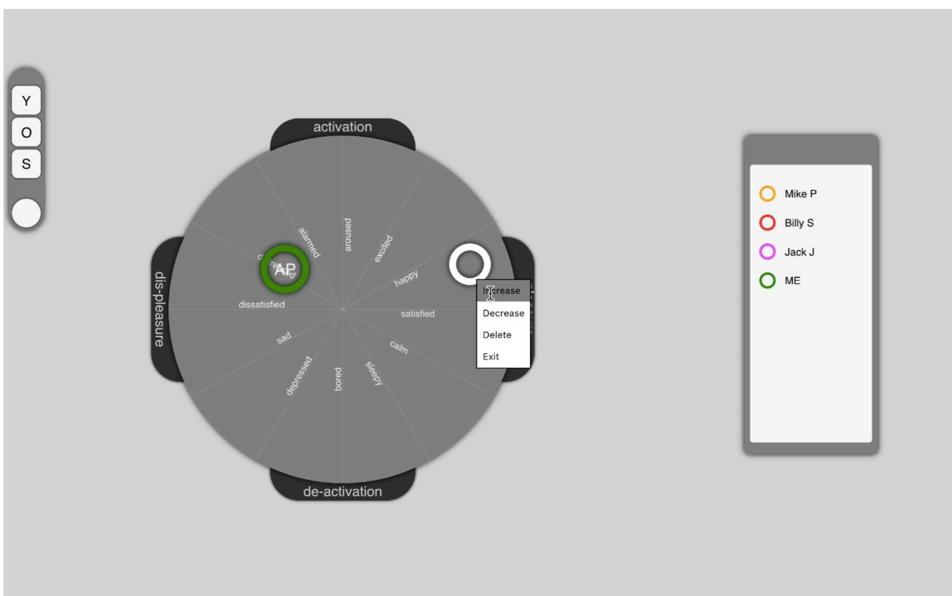
1 The Setup page also allows evaluation of haptic modes based on measurements of the biosensors. Thus what the system stores as personal affective vocabulary will be determined by both the person's physiological reaction to sensory stimuli and their subjective feelings. How the subjective evaluation will be combined with the physiological measurements to determine the person's affective vocabulary will need to be determined in future development of the Affective Matter - Connect interface.

the event through a drop-down menu appearing upon right click in order to adjust the event duration. In further implementation of the interface, on the Setup Page, users could also have the option to send an affective message of specific affective content from a pre-set list which they can edit according to their preferences. For example, the sequence of two fast and strong pressure feelings on the forearm followed by one slower and longer could signify: “I miss you,” “Thinking of you” and so on.

For the UI to be simple and functional, the content-specific emotion events could appear as options in a drop down menu in reference to the location of the events. For example, only contents defined as associated with the feeling of happiness would appear when an event is generated on the Happiness sector of the Affective Wheel. Finally, the user can use an arrow to indicate to whom the user wants to send the emotion event. The arrows are created upon clicking on the components on the Affective Wheel. For example, to send an event to a specific contact, the user first needs to click on the circle with the contact’s initial and then to the event they want to communicate. In this way, the user can choose to send an event to more than one contact. The user can also choose to delete an event, using the delete option of a drop-down menu appearing upon right-click on the event. Finally, the user can remove a contact form their current connections at any time by clicking on the name of the contact on the Contact Panel.

FIG III. 13
The user can see their own affective state on the Affective Wheel (green circle with initials). In the Contact Panel the user can see a list of all available contacts they can connect with. The user can also choose to send an emotion event (black circle)

FIG III. 14
The user can adjust the location of the emotion event (white circle) and its intensity through a right-click drop down menu



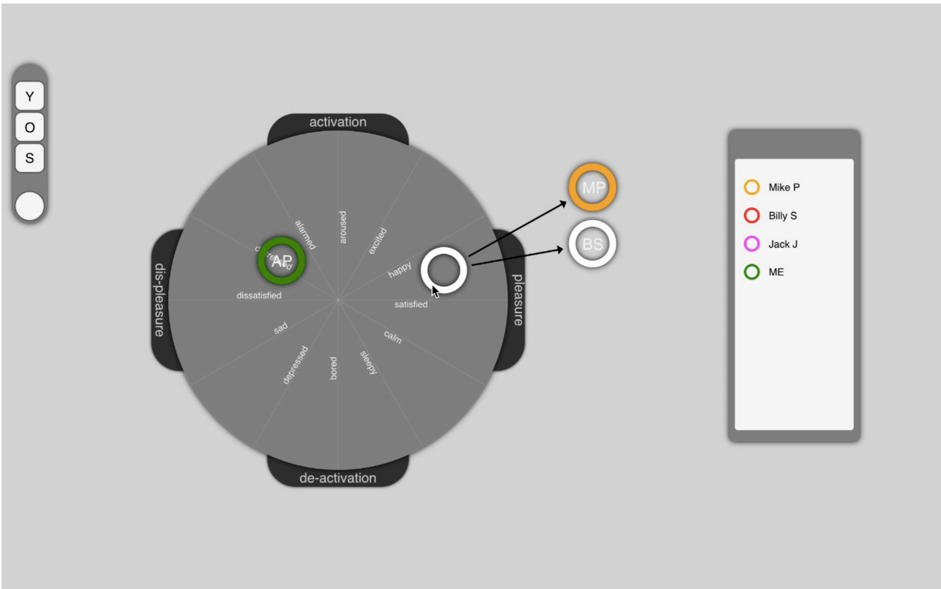


FIG III. 15
The user can choose to send an emotion event to any selected contacts. Once selected from the panel the contacts appear on the periphery of the Affective Wheel. The user then first double-clicks the event and then double-clicks the contact they wish to send the event to.

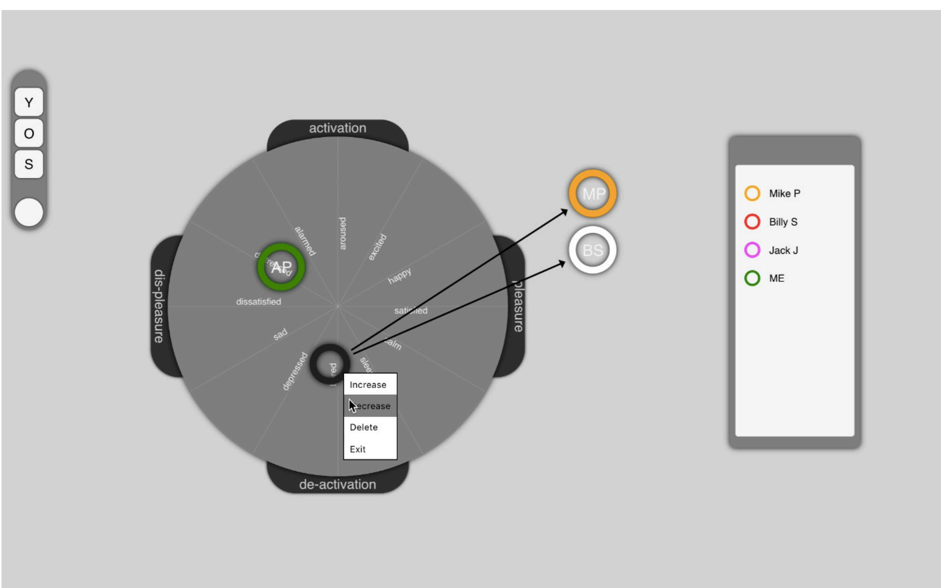


FIG III. 16
The user can adjust the intensity of the emotion event as well as its location in the Affective Wheel thus changing its affective content (e.g. from happy to sad).

FIG III. 17
A user can have a unidirectional or bidirectional communication with selected contacts

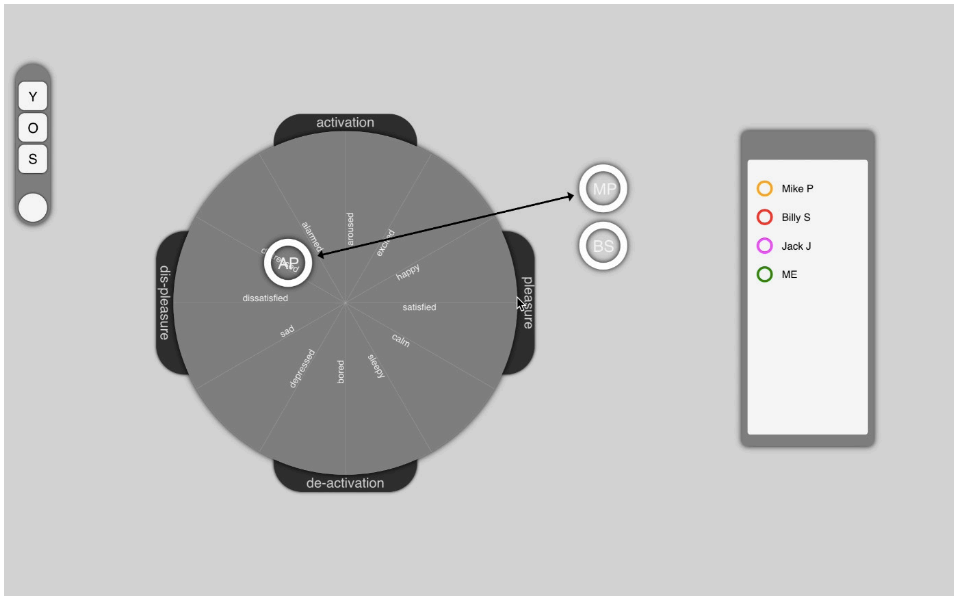
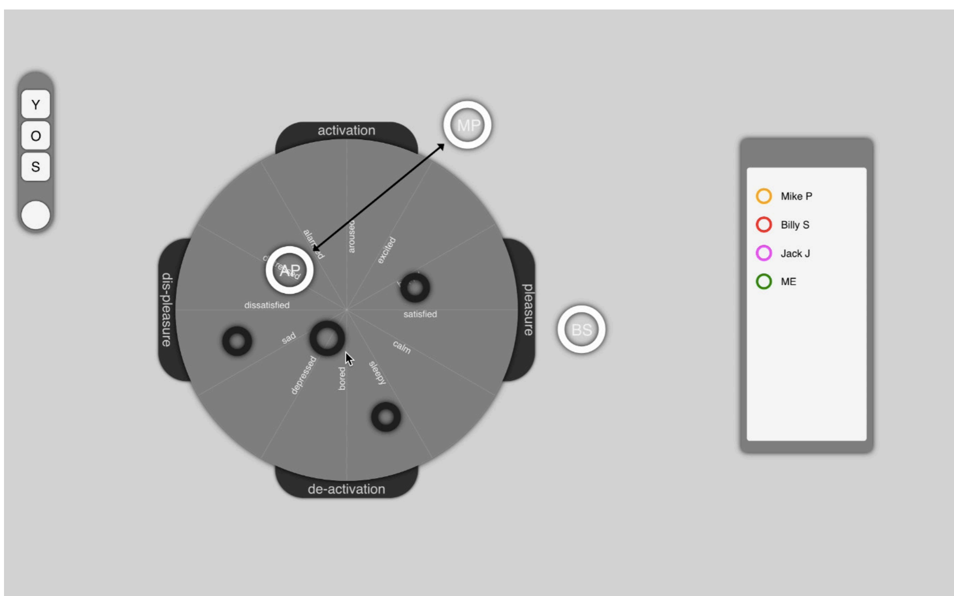


FIG III. 18
A user can create multiple emotion events and adjust their properties



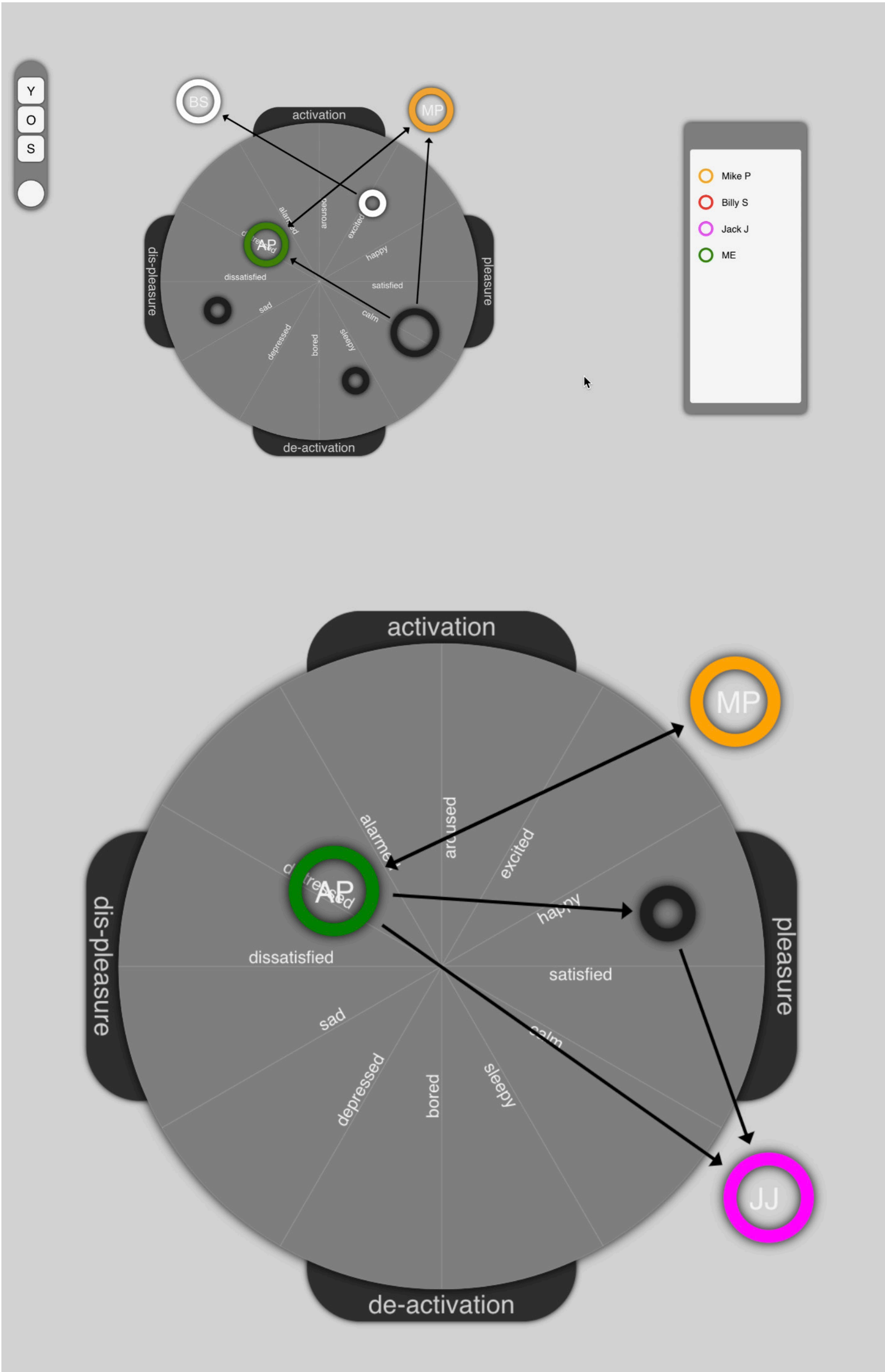


FIG III. 19
A user can connect in unidirectional or bidirectional manner to any of the selected contacts and/or send them emotion events at the same time.

5. Conclusions

Contribution. I developed an interdisciplinary framework in support of material-mediated emotion regulation and communication.

Summary. The framework is composed of theories and studies from a variety of fields, including psychology, neuroscience, aesthetics, design, and theories and history of computing. The first framework chapter examined embodied approaches to emotions. Reviewing emotion theories and philosophies of mind from antiquity to today [chapter 2.1.1], I discussed how in the discourse on emotions, the body was for centuries regarded as being split from the mind and marginalized. It was not until the late 19th century, when Darwin made the evolutionary connection to the expression of emotions and James gave priority to bodily sensations in emotion processing, that the body was given significant attention in psychology studies.

In the second section of the first framework chapter [chapter 2.1.2], I discussed how developments in neuroscience and trauma research demonstrate the importance of embodied awareness in our emotional health, and the role of emotions in our decisions and actions. Antonio Damasio's evidence around his somatic marker hypothesis shows how the body and mind, once thought to be separate from each other, are parts of one whole organism: emotions inhabit the body and emotions are part of reason. I connected Damasio's position to that of Van der Kolk's, who provides an embodied perspective on trauma treatment, emphasizing the role of the body in emotion processes and disorders.

In the first and second sections of the framework chapter [chapter 2.1 and 2.2], the examination of the role of the body in past and current debates on emotion served to demonstrate the need for embodied, bottom-up approaches to emotion regulation. In the third section of the first framework chapter [chapter 2.3], I reviewed two bottom-up mediums for emotion regulation: touch and breathing. I discussed the role of the sense of touch in emotional development and healthy interpersonal relations, and the role of breathing in regulating our emotions as demonstrated through eastern wellness traditions and scientific studies. Touch and breathing are two of the main "ingredients" of the material-mediated emotion regulation and communication method I developed.

In the fourth section of the first framework chapter I explored in greater depth the role of interoceptive (somatic) awareness in emotional awareness [chapter 2.1.4]. I reviewed a series of scientific studies exploring the connection between the lack of awareness of our internal bodily rhythms (e.g. heart rate), emotional awareness, and emotional disorders: limited interoceptive awareness is associated with limited emotion recognition, trauma and other emotional disorders. This review served to support my choice for coupling the rhythms of our body to that of material environments in order to alter or enhance our interoceptive awareness.

In the fifth section of the first framework chapter [chapter 2.1.5], I discussed processes of interpersonal synchrony. Interpersonal synchrony has a significant role in the formation of culture, interpersonal understanding, and empathy. I also extended the discussion of the sense of touch to interpersonal touch and its benefits in terms of both personal and interpersonal emotional wellbeing. This discussion supports the principles of the material-mediated interpersonal communication method I developed: synchronizing our rhythms with that of others through material haptic action can change and/or communicate our emotions as sensory feelings.

In the second framework chapter [chapter 2.2], my goal was to extend the discussion of rhythmic synchrony and its benefits from the synchrony between humans to the synchrony between humans and environments. I first reviewed literature pertaining to Einfühlung, a term used in 19th century German aesthetics [chapter 2.2.1]. Einfühlung, translated as "empathy", meant to resonate and fuse with the object of experience and contemplation. In the second section of the second framework chapter [chapter 2.2.2] I discussed Einfühlung in relation to processes of embedding meaning into objects as they occur during the design process, and to embodied processes that occur in the making process. I referred specifically to the design computing frameworks of Shape Grammars and Making Grammars, as well as other precedents from design and the arts.

The goal of the second section of the second framework chapter [chapter 2.2.2] was to bring the user to the forefront of my inquiry. Some of the theories that I reviewed addressed how subjective meanings are projected and embedded into the object that we experience; others focused on the interplay that occurs between the subject and the object. To further the discussion on dynamic systems whose meaning is generated through an active interaction of the parts and connect them to the aspects of temporal synchrony, in the third section of the second framework chapter [chapter 2.2.3], I discussed definitions of enactive systems, embodiment, and entertainment found in cognitive science and ethnomusicology literature.

In the first section of the third framework chapter I reviewed postwar systems for communication, including Claude Shannon's and Robert Wiener's theories of information, and cybernetic models for self-regulating feedback systems proposed by Ross Ashby and others [chapter 2.3.1]. In the second section of the third framework chapter [chapter 2.3.2], I discussed theories and applications of cybernetic feedback systems to the human body for the purpose of self-regulation. In particular, I discussed Manfred Clyne's concept of the cyborg, which emerged through cybernetic discourse of human-machine adaptive systems and proceeded to Clyne's theory of sentics, which expressed his idea of a universal language of emotions based on their physical and temporal characteristics. This prior work was partly reviewed with critical intentions, implicitly raising again questions of user agency. I then arrived at current models of affective computing which serve as precedents to the material-mediated emotion communication model I proposed [chapter 2.3.3].

Reflections and Future steps. Through a discussion of embodied theories of emotions precedents and evidence from physiology, neuroscience and mental health research, my goal was to demonstrate the opportunities that arise for interactive material systems that target emotional wellbeing. The discussion on subjectivity, agency, and meaning production, was born out of my need to raise and try to respond to questions pertaining to topics such as the following: In a system of human-material interaction, who has the agency -- the material, the individual reacting to the material, or an actor outside the interaction? To what extent does the material determine the affective state of the individual, and to what extent does the individual project their own affective interpretations onto the material?

I have indirectly tried to address such questions through the choices I made for the development of the Affective Sleeves, their evaluation, and Affective Matter interface. In the participant studies, I chose to use bipolar dimensions in the evaluation of affective state, producing a more refined, and ambiguous affective space [chapter 3.2]. My approach reflects a bottom up, user-centered approach of evaluation rather than a top-down rigid framework and follows recent neuroscientific theories supporting various, at least partially distinct affective processes [Norman et al., 2011; Picard et al., 2016]. In the future, additional dimensions could perhaps be added in the evaluation for even more refined results. One multidimensional affective framework often used, named PAD, utilizes the dimensions Pleasure and Arousal and Dominance [Mehrabian and Russell, 1980].

In the controlled studies, the participants did not have much agency in the system because a certain determinism was required to arrive at conclusions. The sleeves were employed as a proof of concept rather than as products being tested by users. My future goal is to explore a sleeve with haptic feedback that can adjust in real-time to the wearer's psychophysiological fluctuations; that is, a system that can be dynamic and respond to the needs of the user. The developed interface described in chapter 3.3, takes into account real-time physiology changes and as many parameters of customization as possible. These pertain to both the wearable material environment and to the affective evaluation of the haptic action. Utilizing a programmable sleeve in conjunction with the developed interface would allow the human-material system to be adaptive and user-driven.

The wearer and the wearable environment could potentially have a dynamic interaction that would allow a certain degree of improvisation; a process of entrainment that would require synchronization but that synchronization would not have to be exact (of the same phase, frequency, or amplitude). A certain repertoire of haptic rhythms and styles could enable different kinds of rhythmic interactions leading to affective changes in the wearer. With regard to rhythmic improvisation, participants' reports in Study II ascribing musicality and playfulness to the sleeve were intriguing. Music metaphors sparked my curiosity about how a creative dialog between the human and the material environment could be explored in the future, and how such dialog could potentially contribute to emotion self-regulation.

Finally, the discussion on computation precedents provided resources for potential future descriptions of the material-mediated affective regulation and communication. For example, I would like to define rules to address the affective change that may occur during one's interaction with Affective Matter. In the Cybernetics framework and the Shape Grammars framework rule-based computations are used to describe transition states of a system, and a shape respectively. In Introduction to Cybernetics, Ashby [1956] utilizes rules of the type A ->B or A<->B to symbolically demonstrate the function of machines with one or two way feedback respectively. In Shape Grammars, and Making Grammars [Stiny 1972; 2006; Knight and Stiny, 2015] replacement rules of the type A -> B are utilized to describe shape transformation based on visual and other sensory processes involved in the creative process. Borrowing methods from the aforementioned frameworks, one of my future goals is to describe computationally the material transformation and affective interaction taking place in material-mediated affective communication.

Contribution. I developed and tested two kinds of programmable affective sleeves, that produce haptic action in the form of warmth and pressure, as examples of Affective Matter.

Summary. I conducted two studies, each using one of the developed affective sleeves. As part of Study I, I designed and developed a sleeve prototype made from shape memory alloys and fabric that produces haptic action, including the feeling of warmth and pressure. When current passes through the nitinol wires that are sandwiched between layers of felt fabric, the wires heat up, producing the feeling of warmth. The temperature change also causes the nitinol wires to change in shape from curved to flat. The shape change of the nitinol wires causes the sleeve's section shape to change from a round to ellipsoid shape, producing a sensation of light touch on the wearer. The feeling of light touch combined with the feeling of warmth define the sleeve's haptic action.

Although shape memory alloys had been previously used in design applications, they had not been used for the purpose of providing haptic action. The challenge in developing a programmable sleeve using a shape memory alloy was the fact that shape memory alloys (at least those available in the market) only allow for a one-way transformation (meaning that the shape change cannot be programmed to be reversible). I demonstrated the limitations of nitinol for reversible shape change, and the details of the method I used to overcome this problem, which consisted of using nitinol in conjunction with fabrics and elastic bands to add mechanical tension to the wire, thus alloying reversible behavior.

The affective sleeve made from fabrics and nitinol wire allowed for sufficient programmability but had the following limitations: the material actuation was impacted by the number of shape- changing repetitions, making the sleeve's behavior unreliable for long-term use; because of the non-reversible nitinol behavior that had to be compensated for via mechanical tension, the sleeve produced only a very light pressure sensation; and due to nitinol's shape-changing behavior in response to temperature, the sensation of pressure could only be produced together with the sensation of warmth.

Because of the limitations in haptic action of the nitinol-based affective sleeve mentioned above, for the second study I designed, developed and tested a programmable pneumatic sleeve with haptic action. The haptic action consisted again of both warmth and pressure, but the two sensations could be controlled independently, as the warmth was produced through embedded heat pads. The sleeve was made of heat-sealable nylon fabrics. The sleeve was designed based on a novel method I developed to program fabrics using pneumatic actuation. The method relies on folding fabrics in a specific manner and constraining them in specific locations.

When a soft rectangular chamber inflates, it tends to straighten due to pressure; this presented a challenge to the design of the sleeve as it produced the opposite result than the one needed in a sleeve with haptic action. In order for a sleeve with haptic action to produce felt pressure, it should not straighten upon pressurization, but should instead curve around the arm in order to push against the skin. Prior methods of programming fabrics to change from a flat to a curved shape upon pressurization did not satisfy the criteria set for the sleeve's haptic action.

This is because if these methods were used for the design of the sleeve, the sleeve would inflate outwards and not towards the skin. As a result, the felt pressure would be limited, and the look of the sleeve distracting, as it would balloon during pressurization.

I developed the programmable pneumatic sleeve using heat-sealable nylon fabrics and sealed them according to the method I developed, so that one side of the material structure is more constrained than the other. Upon pressurization each of the sleeve's cuffs turns from flat and naturally straight, to more voluminous and curved, with the air volume pushing against the skin to create the pressure sensation. The heat pads are embedded within the fabric structure. After repeated use in the controlled studies the sleeve's behavior was unchanged, suggesting that the sleeve's fabrication method is reliable for long-term use.

Reflections and Future Steps. The two programmable affective sleeves I developed demonstrated two cases of a wearable material environment. I chose to develop a sleeve rather than a vest, pant or other huggable object for several reasons. Considering the conducted studies, the sleeve was an easily customizable and modular garment to test on multiple participants. Considering a product, a sleeve is also an easier type of garment (than a vest or pants) to put on and take off as an add-on to one's regular outfit. It is also considerably cheaper than a vest or pants because of the lesser amount of fabrics and electronics required. Another important reason is that, when considering social touch, a mediated touch on the forearm might be perceived as more socially acceptable than a mediated touch on the chest or legs, especially in non-intimate social interactions.

Occupational therapists often use weighted vests to help individuals with sensory processing disorders restore their calmness. The sleeves could offer an alternative form of deep pressure therapy. To my knowledge, no other functional programmable affective sleeves providing warmth and pressure have previously been developed and tested. Of course, as already mentioned, the same method I developed and utilized to make the sleeves can be used to create other wearable material environments such as pants, jackets, socks, pillows, and bodysuits. Several participants in the second study expressed an interest in using a full body garment with haptic action, or sleeves for their legs. In future research, it is worth exploring the Affective Matter form-factor further investigating various types of wearable material environments and their impact on wearers' psychophysiology.

Although several products exist that can promote calmness through pressure, including weighted blankets and vests, the haptic feedback produced by such products is not automated or programmed to respond to individual needs. In the HCI community, researchers have recently started exploring ideas and early prototypes for vests and garments with automated real-time feedback behavior but the solutions have not yet been validated through user testing [Goncu-Berk et al., 2021]. Compared to other products and prototypes, the technology used for Affective Sleeve has the advantage of utilizing both the benefits of deep stimulation, warmth, and breathing regulation. Whereas deep pressure alone, warmth alone, and breathing regulation alone can in principle promote calmness, adding all three together may be a more effective calming method (a hypothesis to be further tested in the future).

A consideration for future work is Affective Matter applications not only for “calming” purposes but also for “arousing” purposes. All prior products and research prototypes discussed so far target stress reduction and the promotion of calmness. However, individuals with trauma, sensory processing disorders and developmental disorders including ASD, can suffer from either hypoarousal or hyperarousal or can alternate between a hypoarousal and hyperarousal state unable to remain in a regulated state in the same manner a “neurotypical” individual would. An important contribution of the affective sleeves I developed and tested is that they can be programmed to promote either a relaxed or an energized state. Thus, an affective sleeve can potentially be developed to respond to one’s hypo-aroused state, one’s hyper-aroused state or both. Existing research on this valuable combined direction seems to be either scarce or lacking.

Investigating applications of the affective sleeve, I conducted a series of interviews with professionals in the field of occupational therapy for sensory processing disorders (SPD) (often tied to trauma, ADD, or ASD). The therapists informed me they often provide a personalized list of activities, to help the individual with SPD regulate their arousal levels. Such a list could include, for example, 10 minutes on a trampoline followed by 30 minutes of wearing a weighted vest and so on. The therapists expressed interest in the fact that the affective sleeve could potentially either stimulate or calm the user, as wearing a sleeve could be part of the “prescribed” activities. User testing in the future with specialized groups of sensitive population is necessary in order to evaluate the benefits of Affective Matter in the form of a sleeve or other wearable for SPD.

In order for the prototype to become a product, several parameters would have to be taken into consideration. In its current state, to facilitate testing and programmability, each cuff of the sleeve is connected to its own mini pressure pump, each connected to a switch. In addition, each of the embedded heat-pads is connected to each own switch. The switches are operated through a microcontroller connected to power. To have a more compact, easily portable version of the prototype, the five mini motor pumps would have to be replaced with one mini electric pump. Such pumps are offered from specialized vendors and have low noise production and power consumption. The air pressure produced by the single pump would be distributed to the cuffs through embedded to the garment electronic switches.

The electronic components can be printed using a customized design and then can either be embedded in the prototype or compose a separate small device to be placed in a pocket or perhaps be worn as a wristband. More challenging to integrate in a sleeve is the breathing sensor, as a breathing sensor of the type used in the conducted studies measures the extension of the chest during inhalation. If such a sensor were used in a future sleeve product it would require a wireless connection to the sleeve. It is not uncommon to have wireless connection to breathing sensors to wearables. Fitness watches continue to offer such solutions for athletes' training, because heart rate and breathing rate measurements are typically more reliable when measured on the chest than when measured on the wrist. Another solution, that would lead to an integrated sleeve prototype, is to use a good Photoplethysmography (PPG) sensor (utilizing measurements under low to no motion conditions) instead of a breathing sensor and infer the breathing rate from blood oxygen concentration [Addison et al., 2015].

Wearables for breathing regulation can more easily integrate a typical BR sensor if they involve the chest as part of the garment as in the case of a vest [Goncu-Berk et al, 2021], or a belt around the chest [Choi et al., 2021]. Moreover, one can potentially take advantage of embedded in fabric electronics to integrate a thin pressure sensor into the fabric. Research in such a direction has very recently been conducted by researchers at the MIT Media Lab who also have combined sensing capabilities with shape changing of the material [Afsar et al., 2021]. It is also worth noting that --in terms of solutions for sensors integration-- researchers on wearables for self-regulation have also been utilizing heart rate measurements instead of breathing rate measurements [Costa et al., 2016]. Research in clothing with haptic feedback is a new, promising research direction as demonstrated by the aforementioned advances in the HCI research community that have succeeded the first publication on the affective sleeve [Papadopoulou et al., 2021].

One limitation in the current development of the prototype, as used in the studies, is that it does not provide real-time haptic feedback. Real-time haptic feedback would be a dynamic haptic response to changes in the psychophysiology of the user. To make the sleeve responsive in real-time, a sensor needs to be worn by the user at all times and be connected wirelessly to the controller of the sleeve. Then, depending on the application, specific algorithms could determine the sleeve's behavior. Maybe the sleeve gets activated only when the arousal levels of the user are below or above a certain defined by the user threshold with the goal to increase or decrease the user's arousal accordingly. Or maybe the user decides a regulation window and the sleeve's task is to keep the arousal levels within that window.

Moreover, one could implement algorithms that could learn from the behavior of the user, adapting the haptic features based on detected physiological responses. For example, the sleeve could detect that a fast pace action with high pressure results in higher arousal levels through the detection of increases in EDA levels or BR. If the user is in a hypo-aroused state and needs to be stimulated by the sleeve, the sleeve could detect that state and apply the learned stimulation mode. Similarly, the sleeve could detect that producing warmth makes the user calm, and apply this mode of haptic action when the user is in a hyper-aroused state. Even though implementing such algorithms is not an especially challenging task, it is questionable whether they would produce the desired results. It is possible that an automated haptic feedback will feel overpowering and controlling to the user. In addition, no matter how refined a training algorithm is, it is very difficult to capture the complexity of real life and complexity of one's emotional state. I would thus be cautious when implementing smart sleeve behaviors for regulating mood.

In the studies I conducted the sleeves did not adapt in real-time to the user's physiology signals. Nevertheless, the results suggested that the sleeve can have an impact on one's psychophysiology even with the preprogrammed personalized settings. This raises the question if the real-time control is even necessary. It is important to keep in mind, when considering these technologies for future products that cost is one of the most important parameters. The smarter and more complicated a device is, the higher the cost. In the field of occupational therapy, as I learned through interviews form therapists in the field, specialized garments and devices are typically not covered by health insurance but are bought at the expense of the school, therapy center, or family.

Although a cyborg-like approach for automated smart clothing that can subliminally take care of our needs may sound technologically attractive it may not be the best approach to the problem of emotion self-regulation. Another parameter to consider, regarding this argument, is the impact of the sleeve or other wearable in self-awareness and self-training. If the sleeve makes all the work for the user without any conscious effort from the user to change affective state, from one perspective an affective sleeve is not very different from taking medication (minus perhaps the side effects). If on the other hand, the user has agency in modifying the behavior of the wearable and can actively engage in the therapeutic human-material interaction process, it is perhaps more likely for the user to understand better what feels right and what does not and how to change that.

Although there are no definite answers regarding future development and applications without user testing, it is my opinion that researchers on future affective garments will have to aim at a fine balance between top-down automation and bottom-up hands-on personalization.

Contribution. I designed and conducted two controlled studies with human subjects, testing the psychophysiological impact of the sleeve. The studies suggested a positive correlation between the pace of the sleeves' haptic action, participants' breathing rate and arousal levels. The studies also suggested a differentiation in the affective response to simultaneous compared to sequential haptic action, as well as to pressure only compared to pressure combined with warmth haptic action.

Summary. The first study (conducted with a collaborator) used the nitinol-based sleeve with haptic action that included both warmth and slight pressure. The study aimed to test the hypothesis that a slow and fast pace of haptic action of the sleeve can increase and decrease respectively participants' psychophysiological symptoms of stress. The fast haptic action was programmed to be 25% faster than the participants' relaxed breathing rate, and the slow haptic action was programmed to be equal to participants' relaxed breathing rate. Participants were randomly assigned to the Slow, Fast and Control groups, where they wore a sleeve with a slow pace of haptic action, a fast pace of haptic action, and no haptic action, respectively. Participants also wore a breathing sensor on their chests and electrodermal activity (EDA) sensor on their wrists.

The study procedure consisted of a baseline, habituation, a practice quiz, a performance task consisting of a scored quiz to induce stress, qualitative surveys and an interview. A comparison between the average difference in EDA levels from baseline to performance task demonstrated a greater increase in the Fast group than in the Regular group, and greater increase in the Regular group than in the Control group. Comparisons of the average change in breathing rates (BR) from the baseline phase to the performance task demonstrated that participants in the Slow group breathed faster than those in the Control Group and slower than those in the Fast Group. The results suggested a positive correlation between the haptic action of the sleeve and participants' breathing rate. However not all results were statistically significant, and, against the study hypothesis, the Control group demonstrated a higher increase than the Slow group.

The results of the physiological data analysis demonstrated a correlation between the pace of haptic action and the participants' breathing rate. Aligned with our expectations, the average increase from baseline to performance task was higher in the Fast group than the Slow group. We also hoped to show that a pace of haptic action equal to relaxed breathing rate could reduce the wearer's breathing rate under stress conditions. However, the fact that the average BR increases from baseline to the performance task was greater in the Slow group than the Control group did not align with our expectations.

The results from the self-reported data suggested a positive correlation between the slow pace of haptic action and perception of calmness and a negative correlation between the fast pace of haptic action and perception of calmness. Participants of the Slow group reported a more positive and comforting experience than participants in the Fast group and participants in the Control group. Participants in the Slow group reported they would be more prone to wearing the sleeve in their everyday life than participants in the Fast and Control groups. This and other results from the analysis of the self-reported data suggest that a slow pace of haptic action may help promote calmness.

The second controlled study I designed and conducted included 36 participants who wore the pneumatic sleeve with haptic action I developed. Participants were randomized to a Regular, Slow and Fast group. The study included a baseline phase, a testing phase of seven haptic conditions, and an interview. The testing of the haptic conditions included pressure and warmth, pressure only, and no pressure or warmth (control), in a randomized sequence. I collected physiology data through an EDA sensor and a breathing activity sensor, and qualitative data through a UI I developed and an interview. Two hypotheses were tested in the study, formulated as follows: (1) the pace of the sleeve's haptic action has a positive correlation with the wearer's breathing rate and a negative correlation with the wearer's perception of calmness; (2) distinct conditions of haptic action are associated with distinct affective states.

The haptic action of the sleeve was programmed based on participants' relaxed breathing rate to be 30% faster for the Fast group, 30% slower for the Slow group, and equal to the relaxed breathing rate for the Regular group. The results of the physiology data analysis, aligned with my hypothesis, demonstrate on average an increase in BR in the participants of the Fast group, and decrease in BR in the participants of the Slow and Regular groups, with the decrease being greater in the Slow group. The results combined demonstrate that haptic conditions with higher changes in BR also were associated with a higher increase in average EDA levels and higher decrease in EDA levels change (slope) within the haptic conditions. The EDA results suggest stronger and brief arousing impact in the Fast group and a lighter and long-lasting calming feeling in the Slow and Regular groups. The BR and EDA results were not tested for statistical significance due to their wide distribution.

Results from the UI surveys and interviews also support the first hypothesis. According to participants' subjective affective evaluation in regard to the Affective Circumplex, the haptic action was perceived as more arousing in the Fast group than in the Slow and Regular groups, and more arousing in the Regular group than in the Slow group. The results also showed that fast pace of haptic action promoted emotions of positive valence, including feelings of excitement. The slow pace of haptic action promoted emotions of slightly negative valence, including feelings of tiredness, yet also feelings of positive valence including feelings of relaxation. Among the three paces of the sleeve, the regular pace of haptic action had the least affective impact.

With regard to the second hypothesis, analysis of participants' testimonies demonstrate that some of the conditions felt more natural and were usually perceived as more pleasant and less distracting, while some felt unnatural and were perceived either as negative and anxiety provoking or as playful. Preferences over sequential and continuous patterns of haptic action were polarized among participants, but conditions including both pressure and warmth were usually perceived as more calming and pleasant than those including only pressure. The perception of warmth and pressure differed according to the pattern of haptic actions: in sequential patterns, the ends of the sleeve were perceived as producing more intense sensation; in simultaneous patterns, the middle of the sleeve was perceived as producing more intense sensations.

Results for both Study I and II combined are aligned with my first hypothesis, as they suggest a positive correlation between the pace of haptic action of the sleeve and participant's breathing rate: the faster the pace of haptic action, the greater the increase in breathing rate. The results of Study I and II combined demonstrate a negative correlation between the pace of haptic action of the sleeve and subjective perception of calmness and tiredness, and positive correlation between the pace of haptic action of the sleeve and subjective perception of stress and/or excitement. The conclusion of the studies is that the sleeve can have an impact on one's psychophysiology, promoting higher or lower arousal states. Further studies need to be conducted to evaluate the statistical significance of these statements.

Reflections and Future Steps. In the conducted studies I utilized certain measures to evaluate affective change and the impact on emotion regulation. These measures included the change of Breathing Rate (BR), the change of Electrodermal Activity (EDA), subjective ratings mapped on the arousal and valence dimension (Study II), multiple choice survey questions (Study I) and subjective reports through interviews (Study I & II). Considering future studies, a question arises regarding which are the minimum requirements in those measures in order to demonstrate an impact on emotion regulation. The answer to this question will help determine future steps of testing Affective Matter.

It is known in medical and physiology research that slow and deep breathing typically corresponds to relaxed states as opposed to fast and shallow breathing which typical corresponds to aroused states [Zaccaro et al., 2018; Russo et al., 2017]. Thus, a decrease in breathing rate may be indication of emotion change from affective states of high arousal (e.g. being excited or stressed) to affective states of low arousal (e.g. being calm or sleepy) [Jerath et al., 2015]. It is also known that higher levels of skin conductance (and/or more fluctuation in the response) typically indicate a state of higher arousal [Turpin and Grandfield, 2007]. Thus, a decrease in EDA levels (and/or decrease in EDA fluctuation), may be an additional indication of emotion change from affective states high arousal to affective states of low arousal states.

A caveat when using physiology measures is that the result of physiological arousal alone does not necessarily reflect a change in one's affective change. For example, if someone is doing physical exercise their BR rate will be fast and their EDA levels high. This fact is one important reason why more than one physiology measure need to be taken as an indication of emotion regulation. It was intriguing for me to observe the difference in the results between Study I and Study II regarding EDA change. Although in Study I a decrease in BR levels seemed to coincide with a decrease in EDA levels (as I had hypothesized), in Study II a decrease in BR levels seemed to coincide with an increase in EDA levels during the testing conditions.

I attributed this difference of the physiological results between the two studies to the difference in the intensity of the haptic stimuli. The pneumatic sleeve produced much greater intensity of pressure and warmth sensations which led to an increase of physical arousal. I concluded that the increase in EDA, when taking into account the BR results, was not an indication of an increase of physical and not of psychological arousal (e.g. feeling of stress or anxiety). My interpretation based on the results is that an affective sleeve can be physically arousing while at the same time psychologically soothing. This is not surprising, when one considers the effect of deep tissue massage on psychophysiology. One might feel a certain physical tension during the massage but relaxation immediately after. Similarly, the increase of EDA levels during testing was immediately followed by a decrease of EDA levels.

I believe that it is important in future studies to keep testing both breathing and electrodermal activity in order to confirm through statistical measures indications offered by the conducted study [Study II]. This would involve repeating the study with an equal number of participants per group, focusing on maybe one of the testing conditions and comparing different paces of haptic action. In addition to the importance of utilizing more than one physiology measure, it is also important to collect self-reports through interviews and surveys. Results for self-reports also help differentiate a change of physiology due to physical activity from a change of physiology as an indication of affective change. In Study II, for example, most participants reported that the feeling of warmth was calming and/or pleasant, and testing conditions including warmth and pressure typically caused greater increase in EDA levels compared to the ones including only pressure.

It must be noted that relying on subjective reports alone may also have limitations, as individuals are not always aware of the changes in their affective states. Regarding this point, it was interesting to observe that although many of the participants reported in the interviews that they found it difficult to evaluate their affective states using the sliders and reported not having significant changes in their mood during the study, the results showed that (contrary to participants belief) there were important changes throughout the study. This raises the question whether a survey particularly regarding Alexithymia should also be included in future studies to evaluate the extent to which participants are aware of their emotions

To sum up regarding measures needed in future studies, I believe BR, EDA and self-reports are required. One can argue that EDA measurements are not really necessary since, in case of the pneumatic affective sleeve, they reflect the physical arousal of squeezing and warmth action. I do not think this is the case; the difference in the change of levels during and after each testing condition was revealing regarding the psychophysiological impact of the sleeve. In addition, often changes in EDA levels (EDA-L) and response (EDA-R) are more noticeable than changes in breathing rate and can thus be a more sensitive measure towards affective response. In future studies, I would use all the aforementioned measurements and reduce the number of conditions to the ones that proved to be more effective in inducing affective change: in study II the most effective were the conditions with simultaneous activation including warmth and pressure (condition 3) and with sequential activation including warmth and pressure (condition 6).

The goal of Study II was twofold. Besides the impact on emotion regulation I wanted to examine the affective response to a variety of haptic stimuli. This second goal, was aligned with my goal to explore the possibilities of Affective Matter as a medium for interpersonal mediated affective communication. As discussed earlier, precedents in mediated social touch not only consist of studies in the actual communication of individuals, but also consist of studies examining the affective response to haptic stimuli. Evaluating materials, textures and other types of haptic stimuli (vibrations, squeezes etc.) in terms of their affective response (arousal, calmness etc.) contributes to the understanding of possible haptic languages for mediated communication through material interfaces.

The reason I included a variety of haptic conditions in Study II was to explore the potentials of the affective sleeve in being used as a medium for affective communication. Proving that different haptic conditions can correspond to distinct affective states, would allow me to build a haptic repertoire to be used for communication purposes. Contrary to the examination of the impact of the sleeve in emotion regulation, which was based on certain established hypotheses regarding specific measures (the fact that high EDA levels typical correspond to high arousal etc.), the examination of the affective responses was purely exploratory. The selection of the specific haptic stimuli included in each haptic condition was not based on predetermined facts and assumptions regarding expected affective reactions. Rather, the examination aimed at exploring what kind of affective differences would result from testing differentiated haptic stimuli, hoping (1) that there will be enough variation in the affective response and (2) that results will lead to useful insights on how to continue testing this parameter in the future.

The study was successful in demonstrating differences in the sensory perception and affective response of simultaneous compared to sequential haptic stimuli as well as in the sensory perception and affective response of pressure stimuli compared to pressure with warmth stimuli. Based on participants' reports in the interview and affective evaluation in the UI, the different conditions were not perceived as significantly different. Also, many participants commented that a greater variety of stimuli might have produced a great variety of responses. Thus, in future studies focusing on the affective response to haptic stimuli one should consider including conditions that differ in multiple parameters.

A recent study using a sleeve with haptic and thermal stimuli showed that movement of pressure stimuli along the forearm creates the illusion of movement of thermal stimuli, a phenomenon called thermal referral [Liu et al., 2021]. This phenomenon could be further explored in the future in conjunction with the affective impact of the affective sleeve and illusions created by the different haptic patterns, as demonstrated in this dissertation and in earlier publication of the work [Papadopoulou et al., 2019]

Last, considering developing the affective sleeve (or other affective material garment) as a product, one should explore further material and functional parameters through user testing. Textiles need to be tested in terms of their possibility to be washable, produce a nice felt experience, be breathable, not producing too much warmth in warm weather, producing warmth in cold weather etc. These parameters become especially important in regard to sensitive and neurodiverse populations as these individuals may be more reactive to certain sensory stimuli. The form factor and easiness to put on or take off the body is also another important parameter, as especially sensitive individuals may feel trapped in a garment or just irritated by the feel or texture of it.

Finally, testing different kinds of garments is important in order to arrive at conclusions regarding the most suitable in specific applications. Maybe a programmable sleeve or vest is more suitable for individuals with trauma, who can benefit from the hugging feeling and perhaps feel more comfortable removing it on demand and controlling it. Maybe a programmable huggable pillow is more suitable for someone with a high level sensory and development disorder who can't easily control a programmable sleeve or vest and remove it on their own.

Contribution. I developed a User Interface for material-mediated emotion communication and regulation that allows the mapping of physiological aspects of emotions to personalized haptic action.

Summary. I designed the interface to have an Interactive Wheel that switches between an Affective and Haptic mode as its main component (built based on the dimensional approach to emotions) and addresses both emotion regulation and communication between two or more users wearing a programmable affective sleeve (or other wearable environment). On the Setup page, the interface addresses user customization by allowing the adjustment of haptic material properties and affective evaluation of the sleeve's haptic action. The interface also allows emotion self-regulation on the Connect-with-Yourself page, which provides the user with suggested Haptic Modes to experience based on their current and desired affective states.

On a Connect-to-Others page, connected users, each wearing a programmable affective sleeve (or other wearable environment) can "locate" each other on the Affective Wheel which visually depicts their current affective state in response to the Arousal and Valence dimensions.

Connected users can exchange affective messages and information regarding their affective state in a one-way or two-way communication. Affective information from the sender is coded into arousal and valence values, and then decoded as haptic action of the receiver's sleeve, based on the receiver's personal material-affective associations.

Reflections and Future Steps. Research on mediated affective communication typically focuses on symbolic haptic representation of affective states rather than on communicating aspects of one's actual psychophysiological state. In the interface I designed, I developed a method to address both aspects, as the user can choose either to communicate aspects of their affective state directly to another user, or send an affective message which has a symbolic haptic representation of affective content. I identified those two communication dimensions and developed a method to express them both through the same tools and affective evaluation methods in the interface. To my knowledge, no previous research on mediated affective communication (or mediated social touch) has aimed at the integration and implementation of both the cognitive and physiological dimension.

The direct communication of aspects of one's affective states happens through a combination of the arousal levels as defined by real-time connected physiology sensors and a combination of the valence levels as defined by user feedback through the interface. This decision, stemming from the intention to personalize and contextualize the parameters of the affective evaluation, has the disadvantage that the user needs to be aware of their valence state and its changes. Another disadvantage is that the user needs to log their valence state frequently in order for the evaluation to be accurate. Perhaps the solution could be to remove the user feedback as part of the evaluation and rely solely on multiple kinds of physiological inputs. The problem in this case is that it would be difficult to contextualize one's situation in order to be able to attribute, for example, one's high EDA levels to excitement, stress, or intense physical activity. Perhaps the user input could be more useful if it addressed not one's mood but one's context: the user could log in their activities, such as reading, running etc., in order to disambiguate the meaningful physiological changes.

No matter how many sensors are added in the system, the system is limited by the fact that it can communicate only some aspects of one's psychophysiological state. The complexity of one's emotional world and social context is impossible to be technologically captured and reduced in just a few dimensions. This limitation does not reduce the value of material-mediated communication through Affective Matter. In my opinion one doesn't need (and should not aim) to capture the entirety of one's internal state for the interface to be useful. Perhaps the mere shared feeling of excitement (as a state of high arousal) expressed as haptic action would be enough to create a shared remote presence and trigger the curiosity of a connected individual to reach out through another modality to understand the context better. Perhaps two connected individuals would already know about each other's context through their everyday interactions and a shared feeling of under-excitement (as a state of low arousal) expressed as haptic action would be already contextualized and thus can be interpreted as calmness, tiredness, or low mood state.

To evaluate the potential impact of material-mediated affective communication via Affective Matter, studies with pairs of subjects will need to be conducted. Different kinds of studies could be conducted in the future to test different hypotheses. A study could be designed to test the specific interface I developed accessing usability parameters and a separate study accessing the success in communication. Regarding the usability parameters the study could focus on the use of the Affective Wheel for the affective evaluation -- as an alternative to virtual switches, or slider nodes. The study focusing on the success of communication could focus on how well the affective meanings sent by one individual in haptic means are perceived and interpreted by another individual.

A study with higher complexity than I was initially planning to conduct is related to the phenomena of interpersonal and physiological synchrony, and emotional contagion. As discussed in earlier chapters, in processes of understanding, and empathizing with another, we tend to synchronize our body movements and physiology with the other. The feeling of touch also contributes in interpersonal and social bonding; a recent study has shown that interpersonal touch causes physiological synchrony, which in turn may enhance empathy [Chatel-Goldman et al., 2014]. To my knowledge no study has yet been conducted to test the impact of mediated social touch in physiological synchrony and the effect this may have on empathy.

The aim of the design of the user interface was not only to aid in the mediated affective interpersonal communication but also to aid in the personalization of the affective sleeve (or other affective garment) for the purpose of emotion self-regulation. Customization of the affective garment is highly important especially when considering applications in different kinds of sensitive populations. Even if focusing only on individuals with anxiety disorders or ASD, each individual may have their own preferences and sensitivities. With regard to ASD, the present interface does present the limitation that requires a labeled interpretation of one's affective state, such as "sad," "happy" etc. This contradicts to some extent the premises of my work which is to focus on the non-verbal sensory-based affective communication. In the future it is worth exploring a design that instead of words (labeling affective states) includes pictorial descriptions of affective states such as emojis as part of the design of the Affective Wheel.

Contribution: I developed Affective Matter as a haptic material modality that allows for material-mediated emotion regulation and communication

Summary. I proposed Affective Matter as a haptic material modality for emotion regulation and communication. Affective Matter demonstrates a means for emotion-regulation and communication through materials. Wearable material environments can be programmed to change shape and properties based on the wearers physiological measurements in order to communicate physiological emotion components through material haptic action. I demonstrated that when the pace of haptic action is programmed in a rhythmic pace that is faster or slower than the wearer's pace of breathing, it can increase or decrease the pace of breathing accordingly, causing change in arousal levels, promoting relaxing or energizing affective states accordingly. I also discussed possibilities of using this method to enhance interpersonal emotion communication through a developed computational model and interface.

Reflections and Future Steps. Affective Matter demonstrates a sensory-based emotion regulation and communication method that harnesses the physical properties of our material environments to promote emotional wellbeing. Affective Matter is the result of a creative synergy between research areas of design, computation, materials and emotions. As architects, designers and researchers we have the responsibility to enhance the world we live in through the sensory and affective qualities of the environments we design.

Since Temple Grandin proposed the first hug machine [Grandin, 1986; 1992], a variety of prototypes and devices have been proposed utlizing deep pressure stimulation to regulate one's affective state. Recently, technological advances in wearable materials and electronics, along with the current commercial interest in personalized health and well-being devices, have led to an increased interest in wearables with sensory feedback. I hope that this work, being one of the first to explore programmable wearable garments with haptic feedback for emotion regulation and communication, will open up more design research avenues in the quest for design tools and methods for emotional wellbeing, neurodiversity and inclusion.

6. APPENDIX

STUDY I: PROCEDURE FORMS

Recruitment Email:

Subject: Participants needed for a study on the effects of rhythmic haptic action on cognitive performance

We are looking for participants to join a 60-minute study to evaluate the effects of touch on cognitive performance. The participants will be asked to take a short spatial cognition quiz while wearing a novel wearable technology with rhythmic haptic action, and biometric sensors to collect physiological signals. Participants will receive a $10 Amazon Gift card for their participation and will have the chance to win an additional $50 if they achieve one of the two highest scores on the spatial cognition quiz.

Participants must be at least 18 years old.

If interested, please email us!

Signed by the investigators

CONSENT TO PARTICIPATE IN
NON-BIOMEDICAL RESEARCH

Psychophysiological response to wearable materials with rhythmic haptic action

You are asked to participate in a research study conducted by PhD student Athina Papadopoulou, Masters student Jaclyn Berry, and Professor Terry Knight from the Department of Architecture at the Massachusetts Institute of Technology (MIT). Please read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

· **PARTICIPATION AND WITHDRAWAL**

In order to participate in the study, you must be between 18 and 65 years old.

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

· **PURPOSE OF THE STUDY**

The purpose of this study is to investigate the effects of rhythmic haptic action (movement and warmth) on cognitive performance.

· **PROCEDURES**

If you volunteer to participate in this study, your participation will include the following:

1. You will wear the E4 sensor on your wrist to collect skin conductance, heart rate, and activity levels (measured through acceleration data) as well as the Zephyr Biopatch sensor on your chest to collect respiration rate and heart rate data. Before beginning the tasks in the experiment, you will do five minutes of mild physical exercise of your choosing such as fast walking, lunges, or climbing stairs to ensure strong biometric signals in the sensor data. If you have any health conditions that would make it unsafe for you to perform such physical exercises, you can skip this part of the procedure and proceed directly with wearing the sensors.

2. You will watch a 15-minute segment of a BBC documentary while wearing the Zephyr Biopatch sensor on your chest and the E4 sensor on your wrist.

3. We will collect data from the Zephyr Biopatch sensor to calibrate the programmable sleeve to your individual biometrics.

4. You will wear the programmable sleeve on your arm. The programmable sleeve is made from fabric and embedded wires. The embedded wires cause the sleeve to rhythmically warm up and move. You will also wear the Zephyr Biopatch chest sensor and the E4 wrist sensor while taking two quizzes:

    a. The first will be a 10-minute practice spatial cognition quiz to become acquainted with the programmable sleeve. This quiz does not count towards your final score.

    b. The second will be a 20-minute spatial cognition quiz to evaluate the effects of the programmable sleeve on your cognitive performance.

5. You will complete two multiple choice questionnaires.

6. You will be briefly interviewed by the experimenters regarding your experience of the study (5 minute interview). If you provide your consent to be audio recorded an audio recording will take place during the interview, otherwise the experimenters will be taking notes.

7. At the end of the study, you will receive a $10 Amazon gift card. You will also have a chance to win an additional $50 Amazon gift card if you achieve one of the two highest scores on the spatial cognition quiz among all participants in the study.

· **POTENTIAL RISKS AND DISCOMFORTS**

The researchers are not clinicians and the physiological data is being collected for research purposes and no clinical inferences will be drawn from it.

The programmable sleeve is not expected to cause any discomfort, however if you have sensitive skin, you may experience some irritation from the fabric. Similarly, the E4 wristband and the Biopatch chest sensor generally do not cause discomfort, but if you have sensitive skin you may notice some irritation from the electrodes.

Should you experience ill effects or have questions/concerns regarding the study, please contact the investigators (information listed at the end of this consent form). If you experience any ill effects (either mentally or physically) during or after the study, inform the investigators immediately.

· **POTENTIAL BENEFITS**

You may appreciate that you are contributing to scientific knowledge regarding sensory feedback and cognitive performance which leads to a better understanding of human physiology and behavior. You may also appreciate that you are contributing to a study exploring the potential of new material technologies promoting wellbeing in society.

· **PAYMENT FOR PARTICIPATION**

You will receive a $10 Amazon gift card at the completion of the study. Participants achieving the two highest scores on the spatial cognition test will receive an additional $50 Amazon gift card.

· **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. In addition, your information may be reviewed by authorized MIT representatives to ensure compliance with MIT policies and procedures.

Identification is not revealed through data recording from the sensors. All data are stored anonymously using numbered codes. The codes are stored by the investigators in a secure location without evidence linking the codes to the recorded data. Questionnaires will also be coded and stored in secure location without evidence linking the codes to the data. Audio recordings from oral interviews, provided you agree to be recorded, will be transcribed and de-identified and audio recordings will be destroyed after being transcribed. Video recordings, provided you agree to be video recorded during the quiz session, will be dissociated from other data and will only be shown in academic settings or public conferences for educational or research purposes. Individual information will not be disclosed in any publication resulting from the study.

All data will only be used for research purposes and will be deleted after 5 years when the outcomes of this study and consequent iterations of this study have been published.

· **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact:

Athina Papadopoulou
Investigator
[redacted]

Jaclyn Berry
Investigator

[redacted]

Terry Knight
Faculty Supervisor
[redacted]

· **EMERGENCY CARE AND COMPENSATION FOR INJURY**

If you feel you have suffered an injury, which may include emotional trauma, as a result of participating in this study, please contact the person in charge of the study as soon as possible.

In the event you suffer such an injury, M.I.T. may provide itself, or arrange for the provision of, emergency transport or medical treatment, including emergency treatment and follow-up care, as needed, or reimbursement for such medical services. M.I.T. does not provide any other form of compensation for injury. In any case, neither the offer to provide medical assistance, nor the actual provision of medical services shall be considered an admission of fault or acceptance of liability. Questions regarding this policy may be directed to MIT's Insurance Office, (617) 253-2823. Your insurance carrier may be billed for the cost of emergency transport or medical treatment, if such services are determined not to be directly related to your participation in this study.

· **RIGHTS OF RESEARCH SUBJECTS**

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143B, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

____ ______________
Signature of Subject or Legal Representative Date

Consent for audio recording

The investigators would like to audio record your 5 min interview at the end of the study. The recording will be destroyed after the interviews have been transcribed by the investigators. The data will be de-identified and remain anonymous. You have the option to not provide your consent. In that case, the experimenters will be taking notes during the interview instead of taking an audio recording. Please sign below if you agree to be audio recorded during the 5 minute interview.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to be audio recorded during the 5-minute interview. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

____ ______________
Signature of Subject or Legal Representative Date

Consent for video recording

The investigators would like to take a video recording of you while taking the spatial cognition quiz and practice test. The video will be dissociated from the rest of the collected data to protect your privacy. The video might be shown in public academic conferences or within academic institutions for educational or research purposes. You have the option to not provide your consent. In that case, no video recording will take *place. Please sign below if you agree to be video recorded while taking the spatial cognition quiz and practice test.*

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to be video recorded while taking the spatial quiz and practice test. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

____ _______________
Signature of Subject or Legal Representative Date

SIGNATURE OF PERSON OBTAINING INFORMED CONSENT

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

____
Name of Person Obtaining Informed Consent

____ _______________
Signature of Person Obtaining Informed Consent Date

Post-Study Debriefing

During this study you were asked to complete a short test while wearing a programmable sleeve with rhythmic haptic action to evaluate your cognitive performance. We measured your physiology (electrodermal activity, acceleration, heart and breathing rate) while you performed this task. In fact, these tests were actually used as part of our study to measure your physiological response to stress with the programmable sleeve. We will analyze your physiological data to evaluate the effects of the programmable sleeve with haptic feedback on your psychophysiological responses with the aim to reduce stress. If you are uncomfortable having your data used for this study after learning its true aims, you are allowed to withdraw your data without any penalty. Furthermore, if you wish to notify COUHES about any discomfort this may cause you, you are invited to contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143B, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to continue my participation in this study. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

____ _______________
Signature of Subject or Legal Representative Date

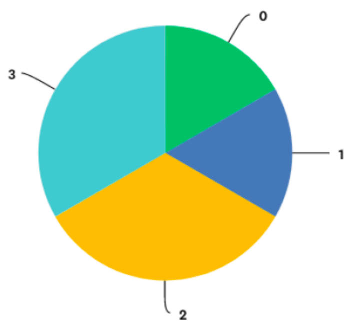
QUALITATIVE SURVEY AND RESULTS

For each question, select a number from 0 to 4 that feels right to you:

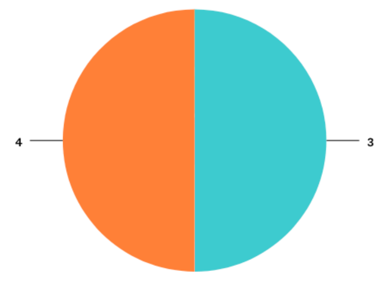
1. Regarding comfort, wearing the programmable sleeve felt:
(0- very uncomfortable, 1- a bit uncomfortable, 2- neither comfortable or uncomfortable, 3-a bit comfortable 4- very comfortable)

0 1 2 3 4

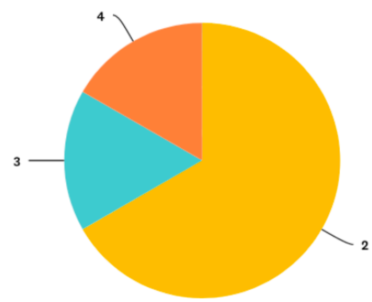
Results



CONTROL



SLOW

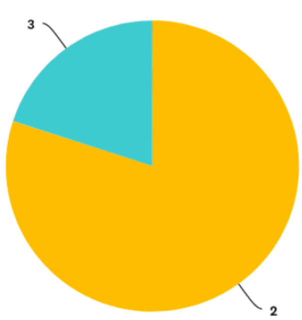


FAST

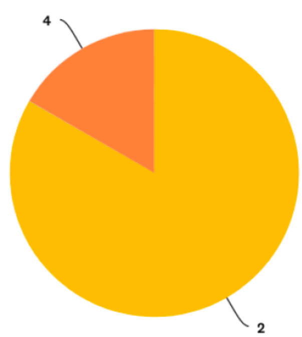
2. Did you feel comfortable with the rhythm of the programmable sleeve (pace of movements and warmth)?
(0- no, I would prefer it much slower, 1- no, I would prefer it a bit slower, 2- yes, it was just right, 3- no, I would prefer it a bit faster, 4- no, I would prefer it much faster)

0 1 2 3 4

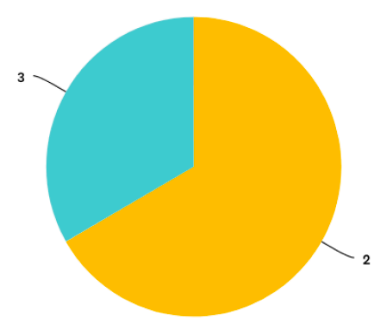
Results



CONTROL



SLOW

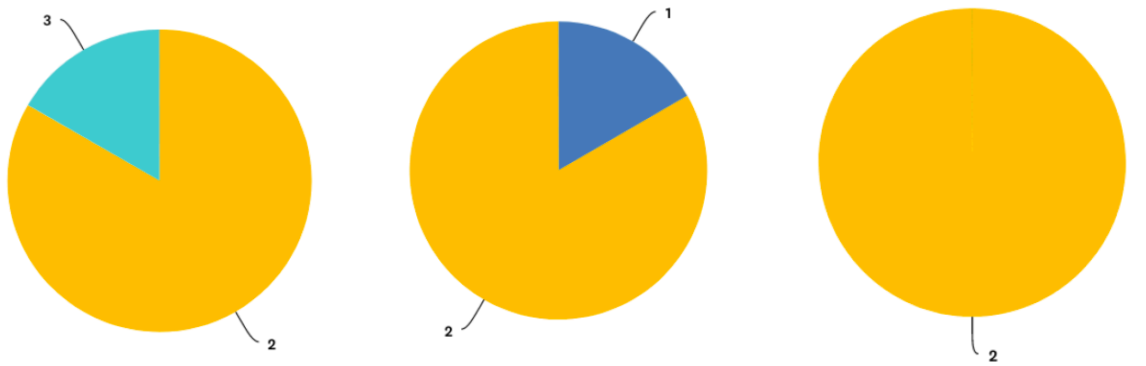


FAST

3. Did you feel that the temperature of the programmable sleeve was:
(0- too warm, 1- slightly warmer than I prefer, 2- just right, 3- not as warm as I prefer, 4- not warm at all)

0 1 2 3 4

Results

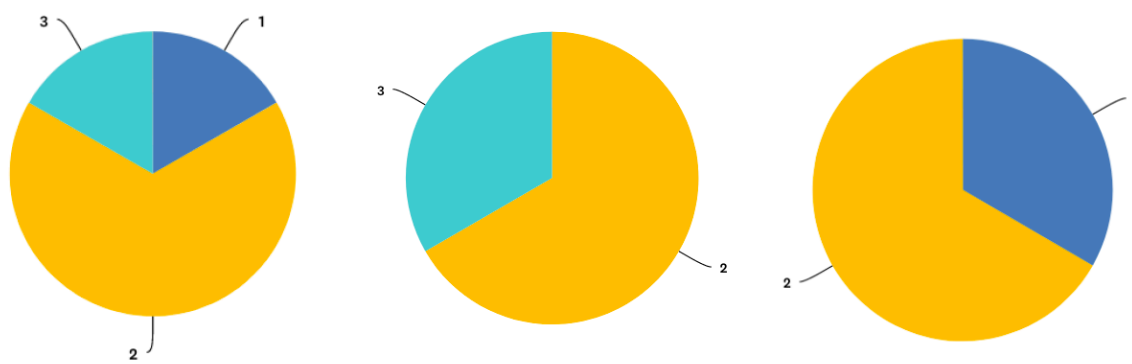


CONTROL SLOW FAST

4. Did you feel that the programmable sleeve was distracting or helped you focus?
(0- it was very distracting, 1-it was a bit distracting, 2- it was neither distracting nor helped me focus, 3- helped me focus a bit, 4- helped me focus a lot)

0 1 2 3 4

Results

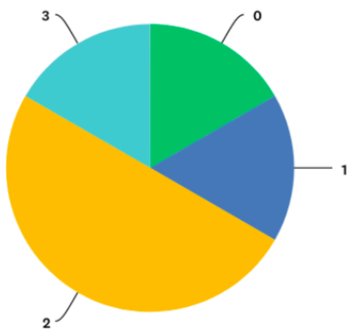


CONTROL SLOW FAST

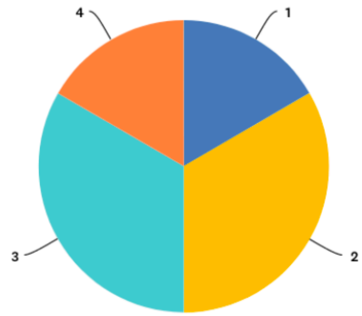
5. Would you wear a programmable sleeve in your everyday tasks if the sleeve proves to increase your cognitive performance ?
(0- no way, 1- probably not, 2- I wouldn't mind, 3- most likely, 4- definitely)

0 1 2 3 4

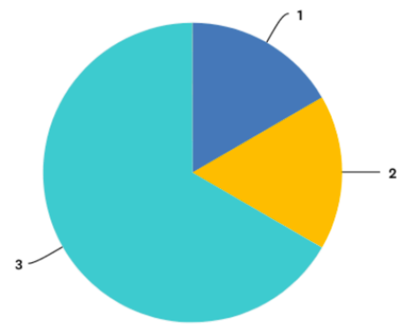
Results



CONTROL



SLOW

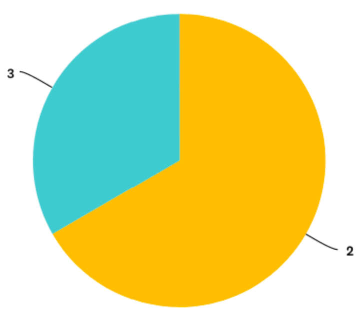


FAST

6. Did you feel that the rhythmic haptic action (both movement and heat) of the sleeve had a stressful or calming effect:
(0- very stressful, 1- a bit stressful, 2- neutral, 3- a bit calming, 4- very calming)

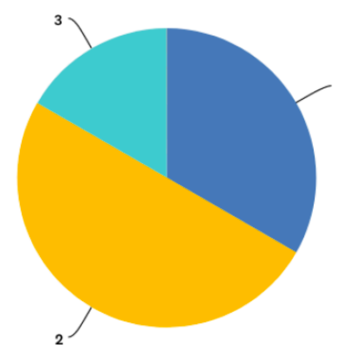
0 1 2 3 4

Results



CONTROL

SLOW



FAST

7. Do you have any comments on the design of the sleeve?

8. How would you describe the sensation of wearing the programmable sleeve?

9. Did you feel that the warmth produced by the sleeve had a stressful or calming effect:
(0- very stressful, 1- a bit stressful, 2- neutral, 3- a bit calming, 4- very calming)

0 1 2 3 4

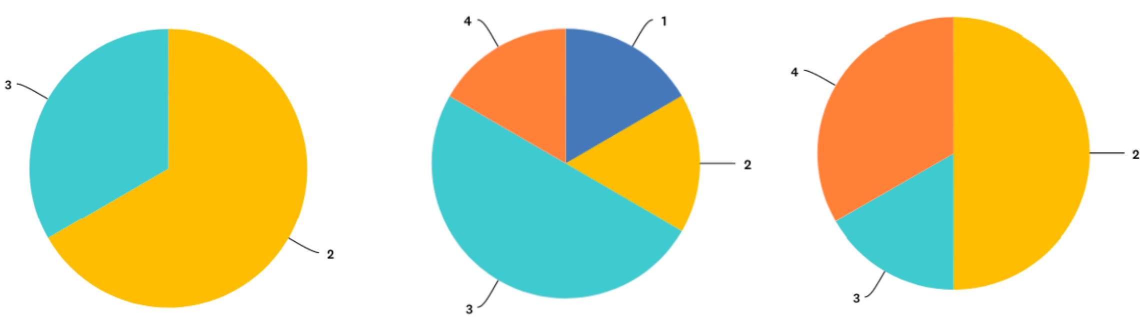
Results

CONTROL SLOW FAST

12. Would you wear a programmable sleeve in your everyday tasks if the sleeve proves to decrease your stress levels?
(0- no way, 1- probably not, 2- I wouldn't mind, 3- most likely, 4- definitely)

0 1 2 3 4

Results



CONTROL SLOW FAST

END OF QUESTIONNAIRE

STUDY II: PROCEDURE FORMS

RECRUITMENT EMAIL

Subject: Participants needed for a study on the emotional impact of haptic sensations produced by wearable materials.

We are looking for participants to join a 65-minute study to evaluate the effects of material haptic sensations on emotional health and wellbeing. The participants will be asked to wear a novel wearable technology that produces the sensations of warmth and slight pressure along their forearm, and biometric sensors to collect physiological signals. Participants will receive $20 via check through the MIT Accounts Payable office for their participation. The study is conducted by Athina Papadopoulou, PhD Candidate in Computation, and supervised by Professor Terry Knight.

Signed by Athina Papadopoulou

CONSENT TO PARTICIPATE IN NON-BIOMEDICAL RESEARCH

Psychophysiological response to wearable materials with rhythmic haptic action producing warmth and slight pressure

You have been asked to participate in a research study conducted by PhD Candidate Athina Papadopoulou and Professor Terry Knight from the department of Architecture at the Massachusetts Institute of Technology (M.I.T.) The results of the study will contribute to research findings of Athina Papadopoulou's PhD dissertation.

You were selected as a possible participant in this study because you satisfy the eligibility criteria and showed interest to participate.

The information below provides a summary of the research. Your participation in this research is voluntary and you can withdraw at any time.

- **Purpose**
  The purpose of this study is to investigate the emotional impact of warmth and slight pressure sensations produced by a programmable wearable sleeve.
- **Study Procedures**
  In this study you will be asked to wear a programmable sleeve producing slight warmth and pressure sensations, a sensor on your fingers measuring your electrodermal activity and a sensor on your chest measuring your heart and breathing activity. You will also be asked to evaluate the sensations produced by the sleeve and the emotions associated with those sensations in self-report forms and a brief interview.
- **Risks & Potential Discomfort**
  The programmable sleeve and sensors you will wear are not expected to cause any discomfort. If, however you feel any discomfort for any reason (due to irritation of sensitive skin or any other unexpected inconvenience) you should notify the investigator.

You should read the information below, and ask questions about anything you do not understand before deciding whether or not to participate.

- **PARTICIPATION AND WITHDRAWAL**

In order to participate in the study, you must be between 18 and 65 years old.

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. The investigator may withdraw you from this research if circumstances arise.

- **PURPOSE OF THE STUDY**

The purpose of this study is to investigate the emotional impact of warmth and slight pressure sensations produced by a programmable wearable sleeve.

- **PROCEDURES**

The duration of the study is 65 minutes. If you volunteer to participate in this study, we would ask you to do the following (if you provide your consent to be video recorded, the procedure will be video recorded):

1. **Wearing the Sensors** You will wear the Midfield E-sense Skin Response sensor on your fingers to collect Electrodermal Activity Data (EDA) and the Zephyr Biopatch sensor on your chest to collect respiration rate and heart rate data. You will be asked to sit on a chair.
2. **Adjusting the Sensors** You will be asked to relax for 5 minutes. During that time, we will be collecting data from the Zephyr Biopatch sensor to calibrate the programmable sleeve to your individual biometrics.
3. **You will wear the programmable sleeve on your arm.** The sleeve is made from inflatable and other fabrics and has embedded heating pads. The inflatable fabrics cause the sleeve to change shape inducing slight pressure, no greater than a common blood pressure cuff, and the heating pads cause the sleeve to produce slight warmth of 104 Fahrenheit maximum temperature, which is comparable to the water temperature of a warm bath, and lower than the maximum temperature of commercial heating pads for relaxation. You will continue to wear the E-sense Skin Response and Zephyr Biopatch sensors. While continuing to be seated on the chair you will feel different types of sensations produced by the sleeve, which will consist of warmth and/or pressure or combinations of these on various locations along the forearm in various speeds:

   a. First you will experience a sample of different sensations produced for 3 minutes, to get familiar with the sleeve.
   b. Then, you will experience 9 different types of sensations produced by the sleeve each in different sessions. Each session will last 3 minutes. Before and after each of the session there will be a pause for 1.5 minutes. During that time the sleeve wont produce any sensations. During that time, before and after each session, you will be asked to fill-out a self-report regarding your felt emotions at the moment and a self-report indicating on a diagram the types of sensations you felt.

4. You will be interviewed briefly interviewed by the experimenters regarding your experience of the study (3 minutes interview). If you don't provide your consent to be video recorded, you may provide your consent to be audio recorded for this step for the procedure. Otherwise, the experimenters will be talking notes during the interview.

5. After the interview you will be informed by the experimenters regarding the purpose and expected results of the study in more details, and have the opportunity to ask questions

regarding the study.

6. You will receive $20 via check through the MIT Accounts Payable office after the completion of this study as a compensation for your participation.

- **POTENTIAL RISKS AND DISCOMFORTS**

The researchers are not clinicians and the physiological data is being collected for research purposes and no clinical inferences will be drawn from it.

The programmable sleeve is not expected to cause any discomfort. However if you have sensitive skin, you may experience some irritation from the fabric. Similarly, the Midfield E-sense Skin Response sensor and the Zephyr Biopatch chest sensor generally do not cause discomfort, but if you have sensitive skin you may notice some irritation from the electrodes.

Should you experience ill effects or have questions/concerns regarding the study, please contact the investigators (information listed at the end of this consent form). If you experience any ill effects (either mentally or physically) during or after the study, inform the investigators immediately.

- **POTENTIAL BENEFITS**

You may appreciate that you are contributing to scientific knowledge regarding the emotional impact of haptic sensory stimuli, which leads to a better understanding of human physiology and behavior. You may also appreciate that you are contributing to a study exploring the potential of new material technologies promoting wellbeing in society.

- **PAYMENT FOR PARTICIPATION**

You will receive $20 via check through the MIT Accounts Payable office after the completion of this study.

- **PRIVACY AND CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. In addition, your information may be reviewed by authorized MIT representatives to ensure compliance with MIT policies and procedures.

All electronic data will be password protected and encrypted. All paper data will be kept in a locked cabinet in a locked office. Identification is not revealed through data recording from the sensors. All data are stored anonymously using numbered codes. The codes are stored by the investigators in a secure location without evidence linking the codes to the recorded data. Questionnaires will also be coded and stored in secure location without evidence linking the codes to the data. Audio recordings from oral interviews, provided you agree to be recorded, will be transcribed and de-identified and audio recordings will be destroyed after being transcribed. Video recordings, provided you agree to be video recorded, will be dissociated from other data and will only be shown in academic settings or public conferences for educational or research purposes. Videos containing faces might be published in public presentations. Individual information will not be disclosed in any publication resulting from the study.

All data will only be used for research purposes and will be deleted after 5 years when the outcomes of this study and consequent iterations of this study have been published.

- **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact:

Athina Papadopoulou
Investigator
[redacted]

Terry Knight
Faculty Supervisor
[redacted]

- **EMERGENCY CARE AND COMPENSATION FOR INJURY**

If you feel you have suffered an injury, which may include emotional trauma, as a result of participating in this study, please contact the person in charge of the study as soon as possible.

In the event you suffer such an injury, M.I.T. may provide itself, or arrange for the provision of, emergency transport or medical treatment, including emergency treatment and follow-up care, as needed, or reimbursement for such medical services. M.I.T. does not provide any other form of compensation for injury. In any case, neither the offer to provide medical assistance, nor the actual provision of medical services shall be considered an admission of fault or acceptance of liability. Questions regarding this policy may be directed to MIT's Insurance Office, (617) 253-2823. Your insurance carrier may be billed for the cost of emergency transport or medical treatment, if such services are determined not to be directly related to your participation in this study.

- **RIGHTS OF RESEARCH SUBJECTS**

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of

Humans as Experimental Subjects, M.I.T., Room E25-143B, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

______________________________________ ______________
Signature of Subject Date

____ ______________
Legal Representative (if applicable) Date

Consent for audio recording

The investigators would like to audio record your 5-minute interview at the end of the study. The recording will be destroyed after the investigators have transcribed the interviews. The data will be de-identified and remain anonymous. You have the option to not provide your consent. In that case, the experimenters will be taking notes during the interview instead of taking an audio recording of you while participating in the study. Please sign below if you agree to be audio recorded during the 5-minute interview.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

______________________________________ ______________
Signature of Subject Date

____ ______________
Legal Representative (if applicable) Date

Consent for video recording

The investigators would like to take a video recording of you while participating in the study. The video will be dissociated with the rest of the collected data to protect your privacy. The video might be shown in public academic conferences or within academic institutions for educational or research purposes. You have the option to not provide your consent. In that case, no video recording will take place. Please sign below if you agree to be video recorded during the study.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

______________________________________ ______________
Signature of Subject Date

____ ______________
Legal Representative (if applicable) Date

SIGNATURE OF PERSON OBTAINING INFORMED CONSENT

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

____
Name of Person Obtaining Informed Consent

____ ______________
Signature of Person Obtaining Informed Consent Date

POST-STUDY DEBRIEFING

During this study you were asked to were a programmable sleeve with rhythmic haptic action to evaluate the emotional impact of haptic sensations produced by the sleeve. We measured your physiology (electrodermal and breathing activity) while you were wearing the sleeve. We also asked you to fill-out self-reports regarding your subjective feelings in response to the sleeve's haptic action. We will analyze the self-reported and physiological data to evaluate the effect of the programmable sleeve with haptic action on your psychophysiology, particularly its impact on any felt emotions. If you are uncomfortable having your data used for this study you are allowed to withdraw your data without any penalty. Furthermore, if you wish to notify COUHES about any discomfort this may cause you you are invited to contact the Chairman of the Committee on the Use of Humans as Experimental Subjects MIT Room E25 143B 77 Massachusetts Ave Cambridge MA 02139, phone 1-617-253-6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to continue to have my data used in this study. I have been given a copy of this form.

____

Name of Subject

____

Name of Legal Representative (if applicable)

____ ______________

Signature of Subject or Legal Representative Date

Outline of Oral Interview

1. How would you describe the experience of wearing a programmable sleeve with haptic action?

2. Do you have any comments regarding the sensations (warmth and/or slight pressure) produced by sleeve? Was there a considerable difference in felt sensations in the various conditions of haptic action you experienced? If so, could you elaborate more?

3. Do you have any comments regarding any emotions you felt due to the haptic action of the sleeve? Think of the different conditions of haptic action you experienced, was there a considerable difference in the way these made you feel? If so, could you elaborate more?

4. Do you have any comments regarding the design of the sleeve?

5. Would you wear a programmable sleeve with haptic action if it proved to improve your wellbeing, for example reduce your stress levels? If not, what do you think needs improvement?

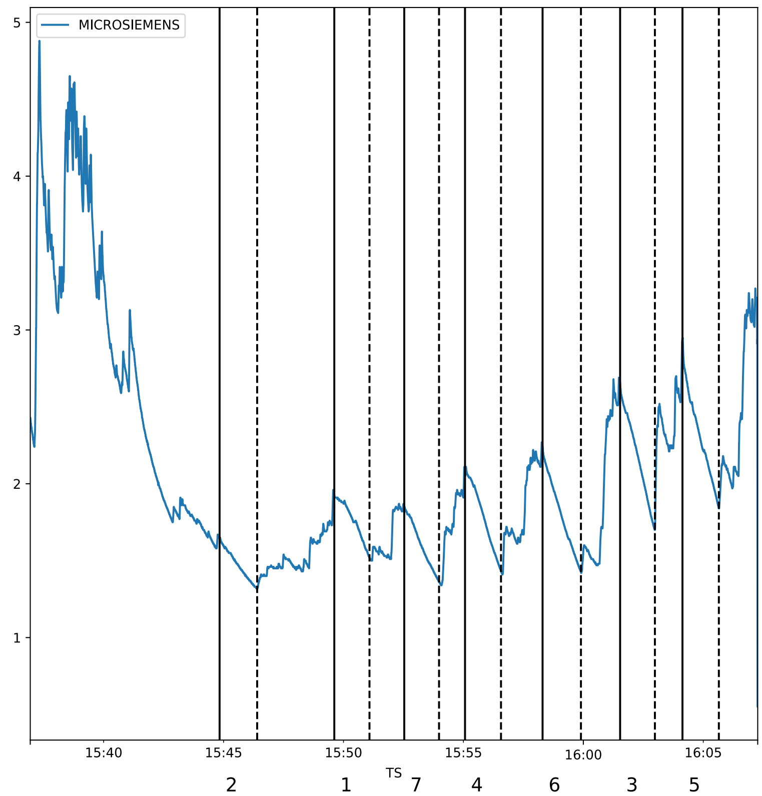
6. Do you have any comments regarding the study procedure?

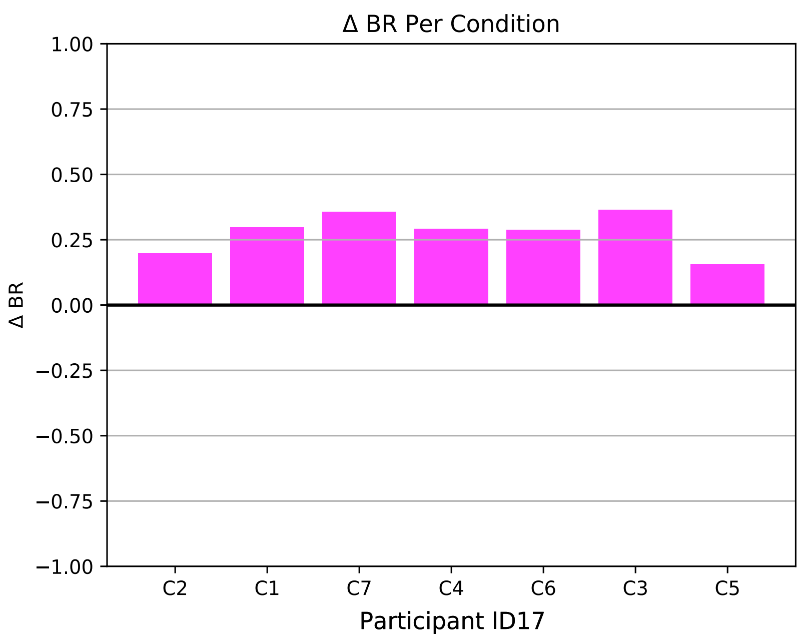
7. Do you have any questions regarding the study and its goals? If so, I can provide you now with more information.

Questions might be asked in a different order. Clarifying questions after each question might be used depending on the answer of the participant.

STUDY II: PHYSIOLOGICAL DATA PER PARTICIPANT

ID 17 REGULAR GROUP





The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

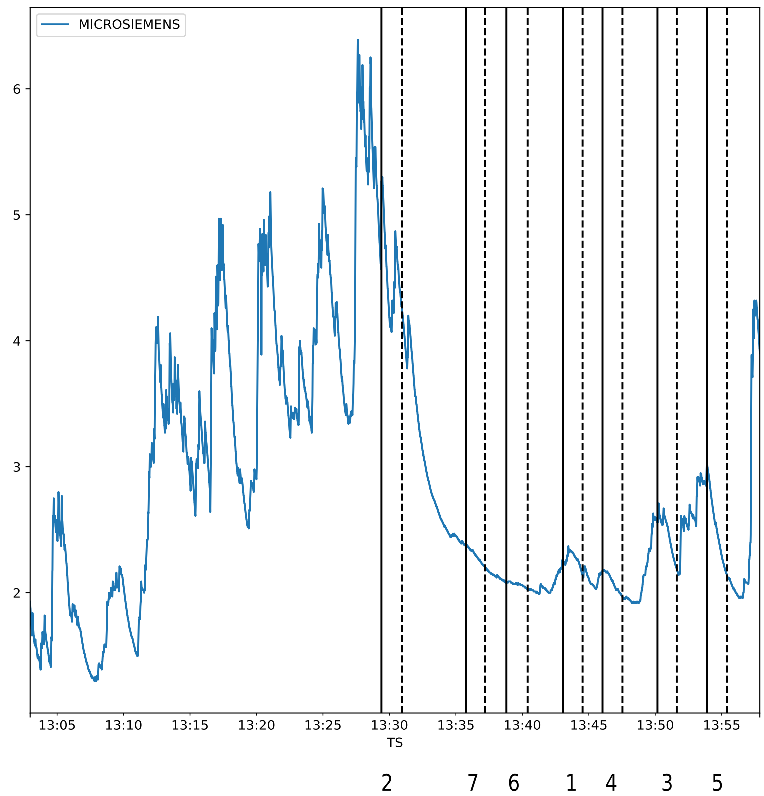
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

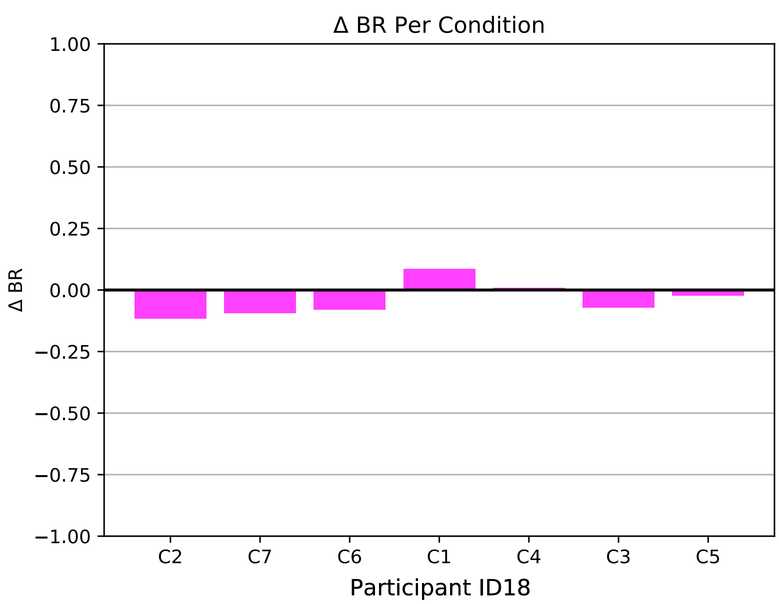
ID 18 REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

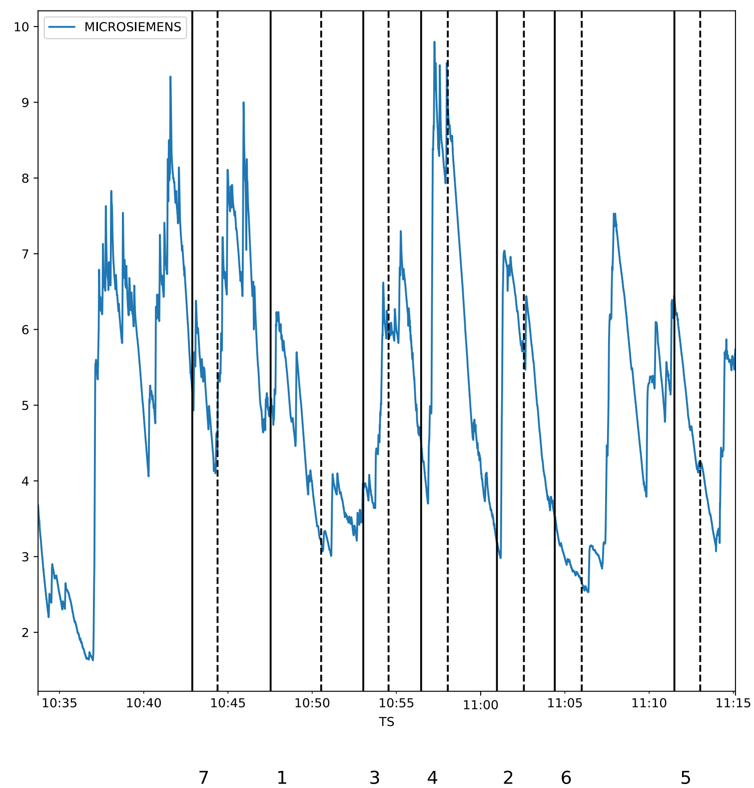
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

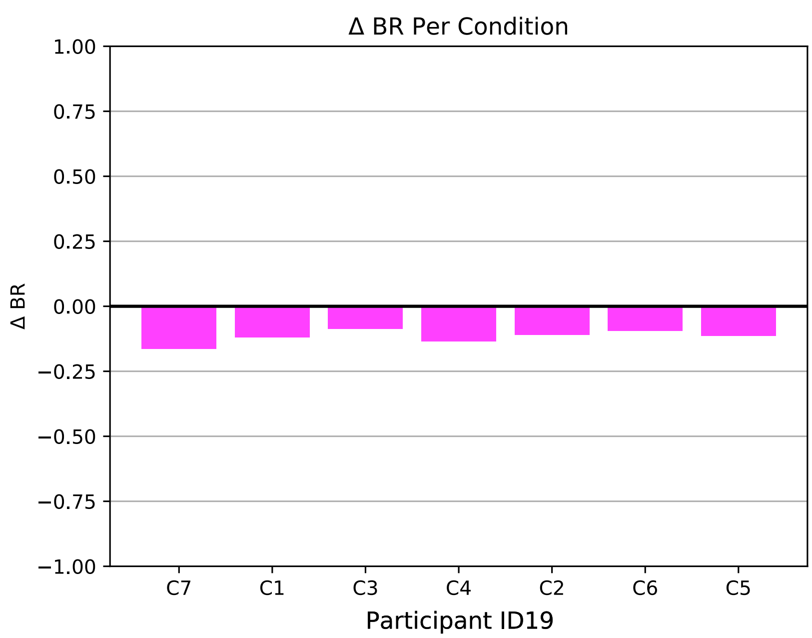
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.





ID 19
SLOW
GROUP





The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

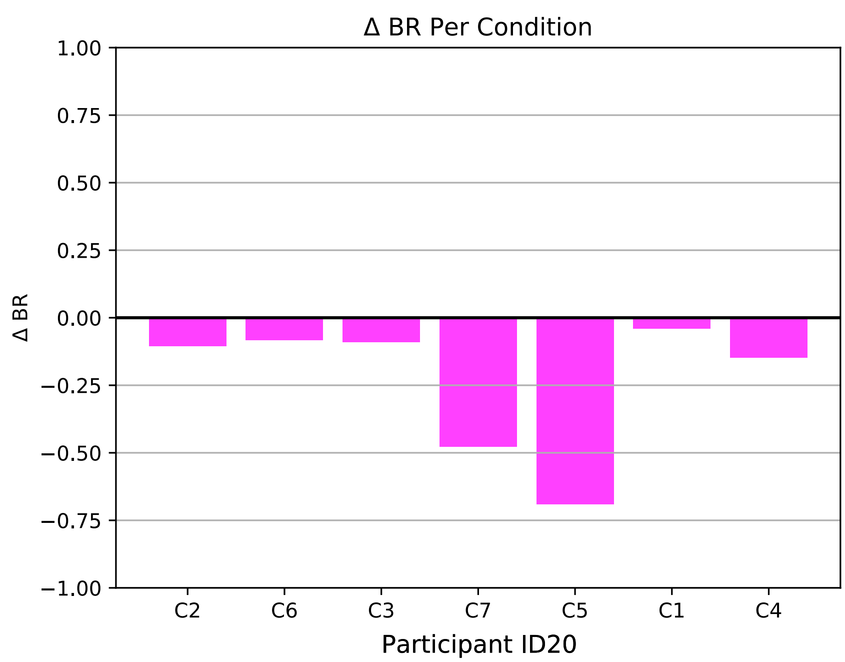
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

ID 20
REGULAR
GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

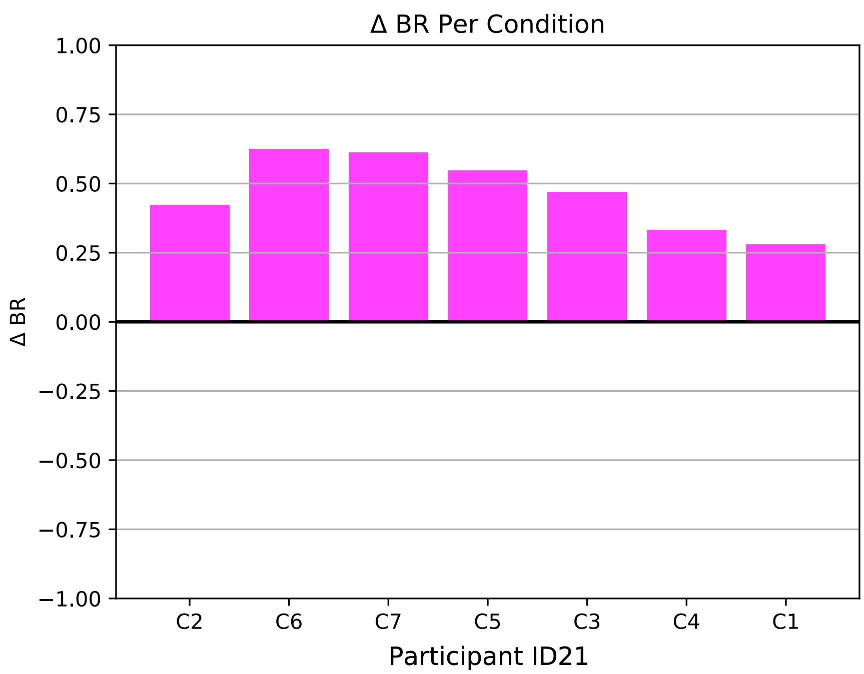


ID 21 REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

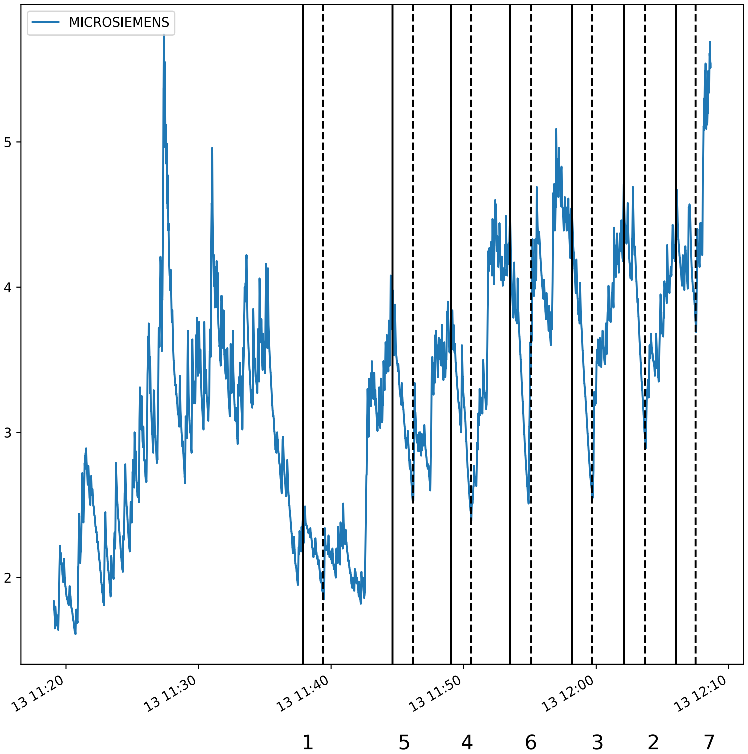


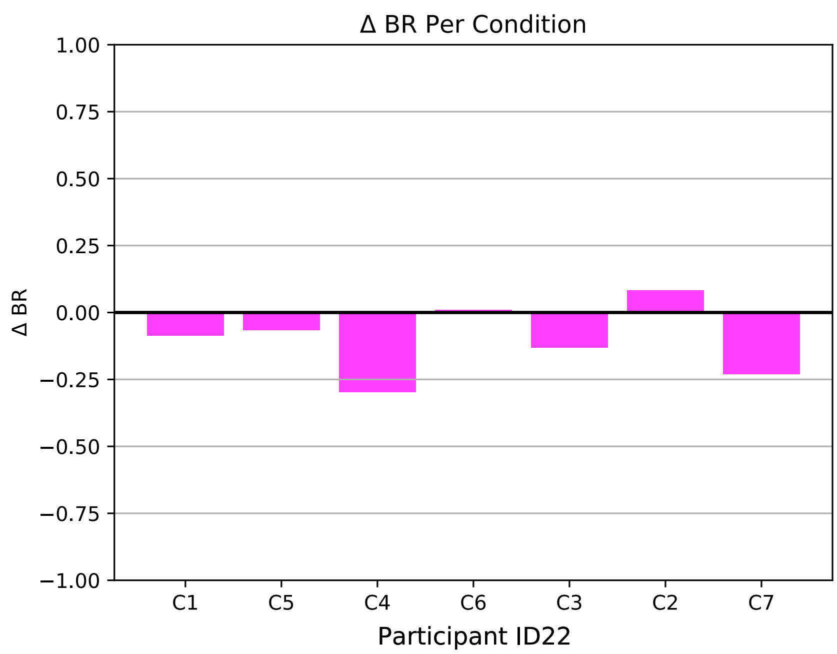
ID 22 SLOW GROUP

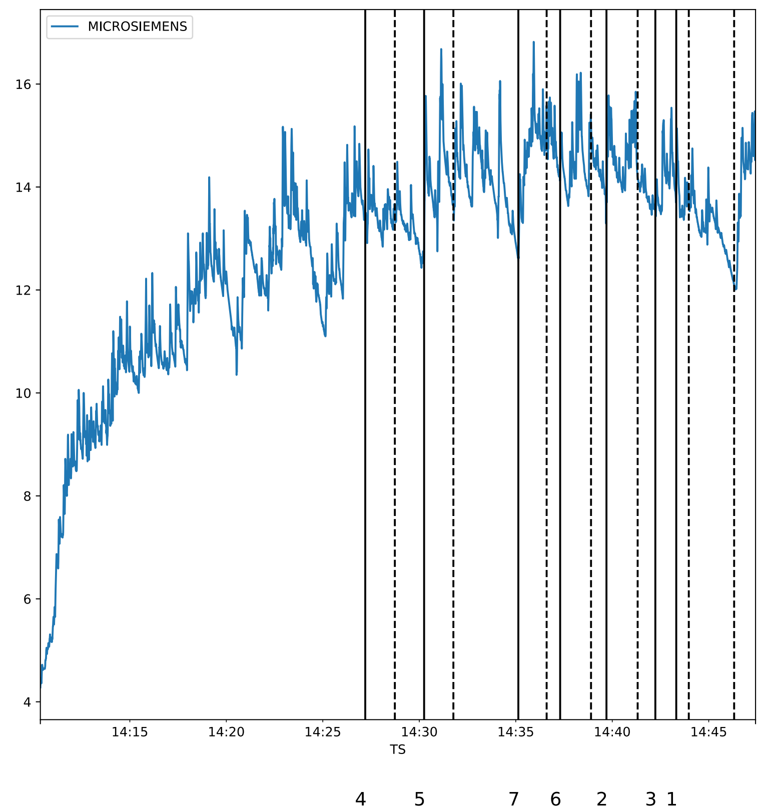
The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

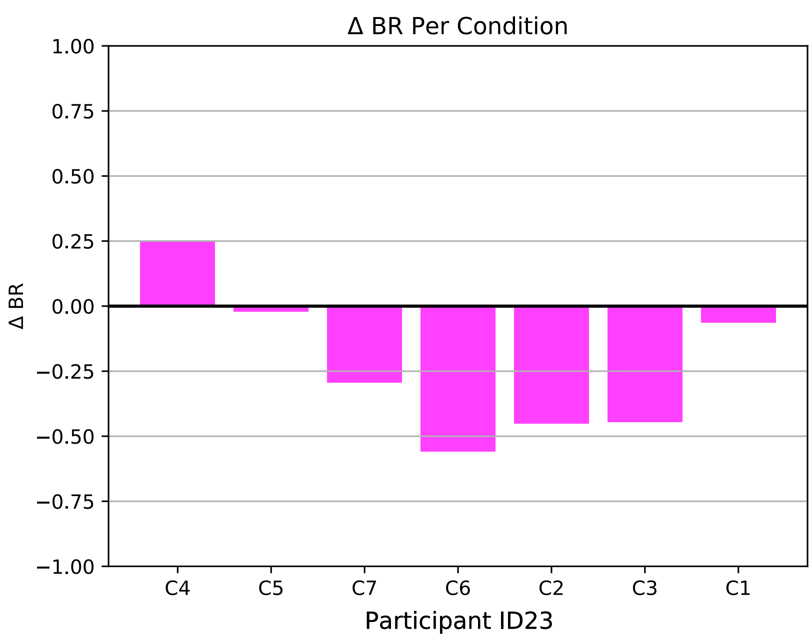
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.









ID 23 REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

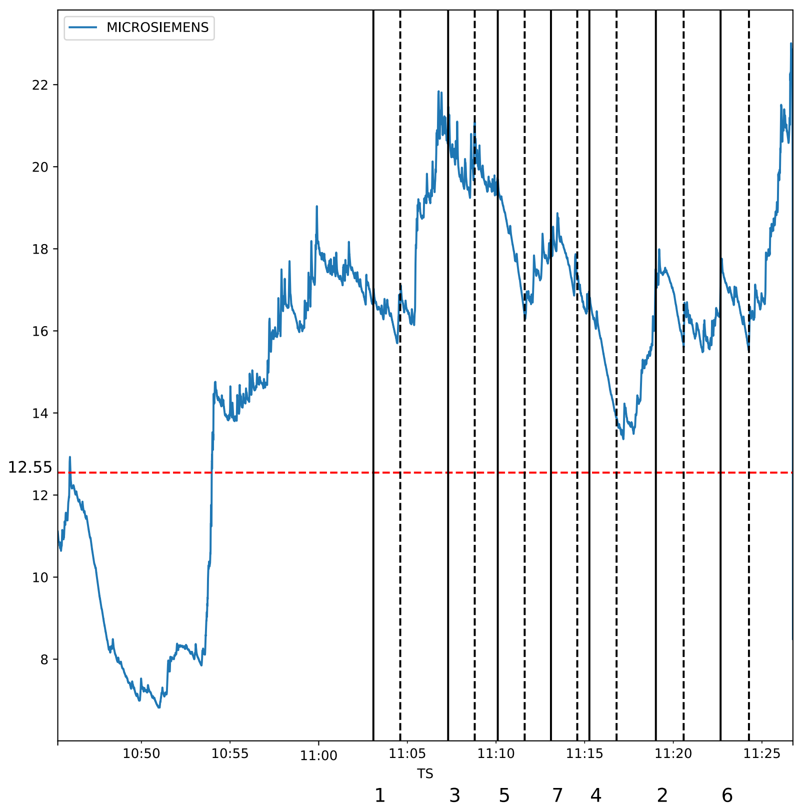
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

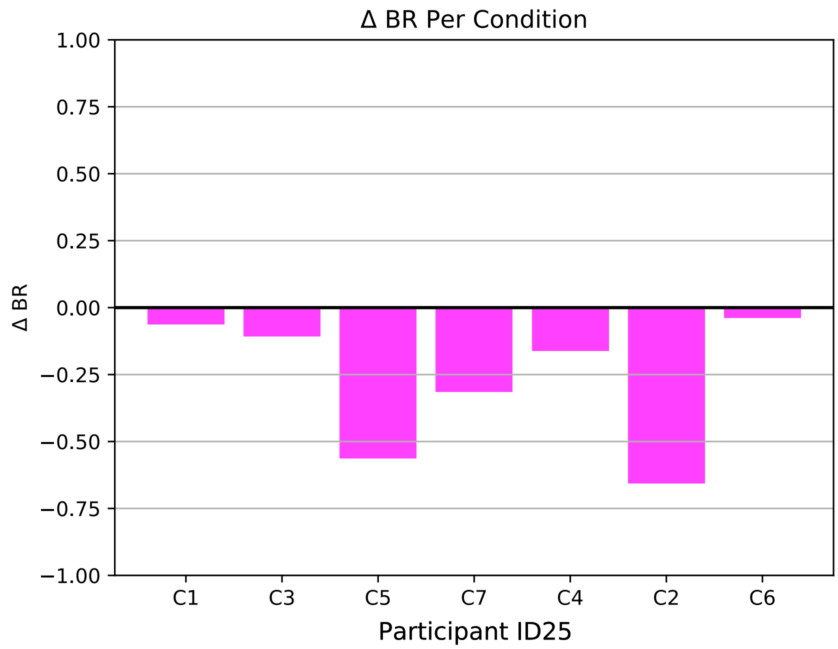
ID 25
REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

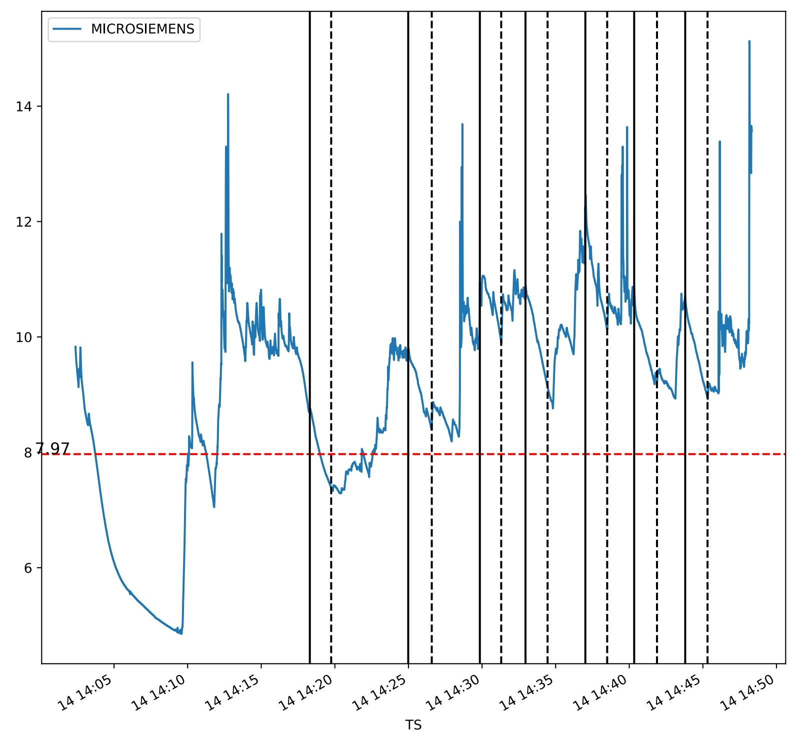
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

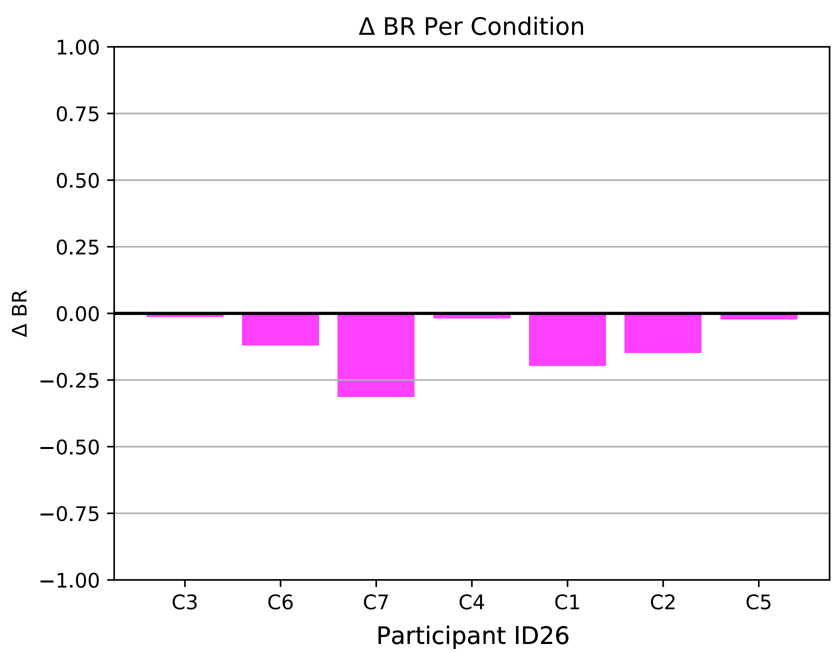




ID 26
SLOW GROUP



3 6 7 4 1 2 5



The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

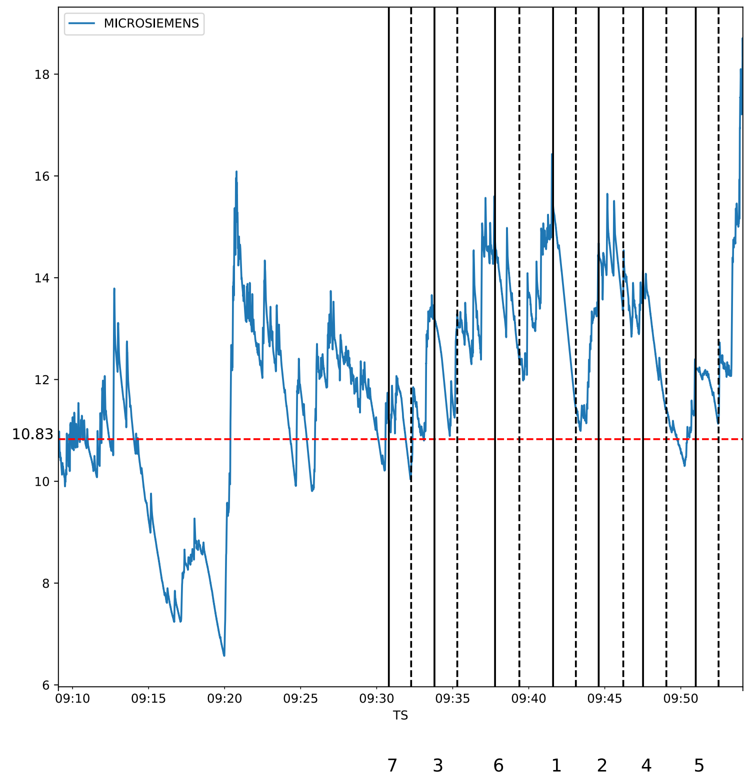
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

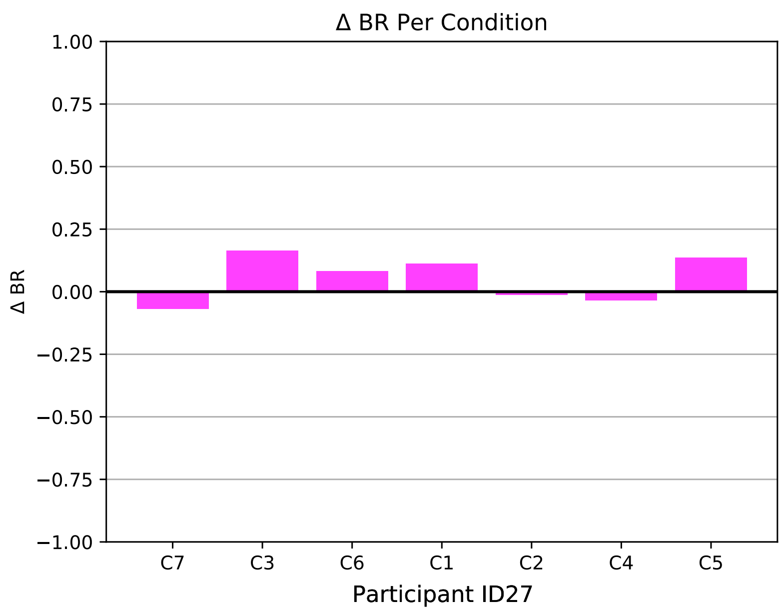
ID 27 SLOW GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

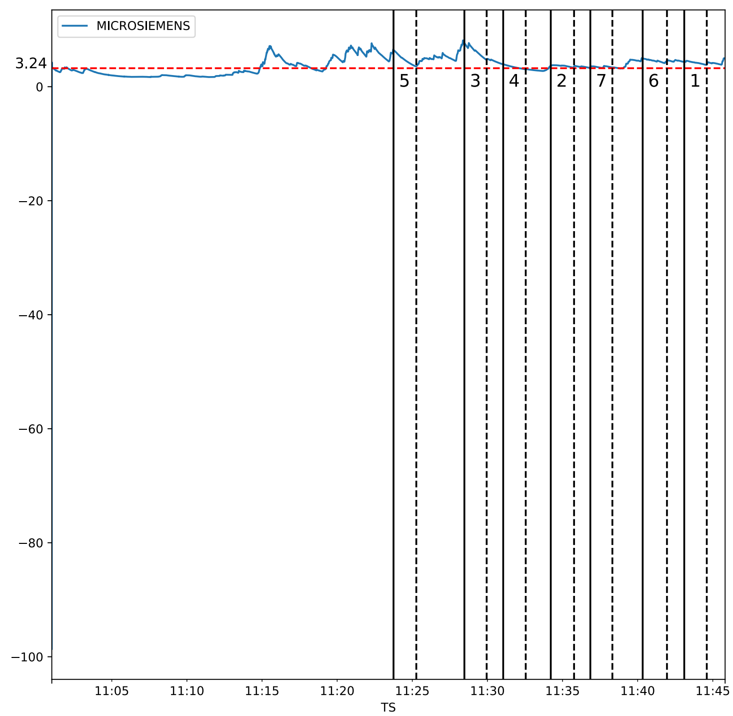
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

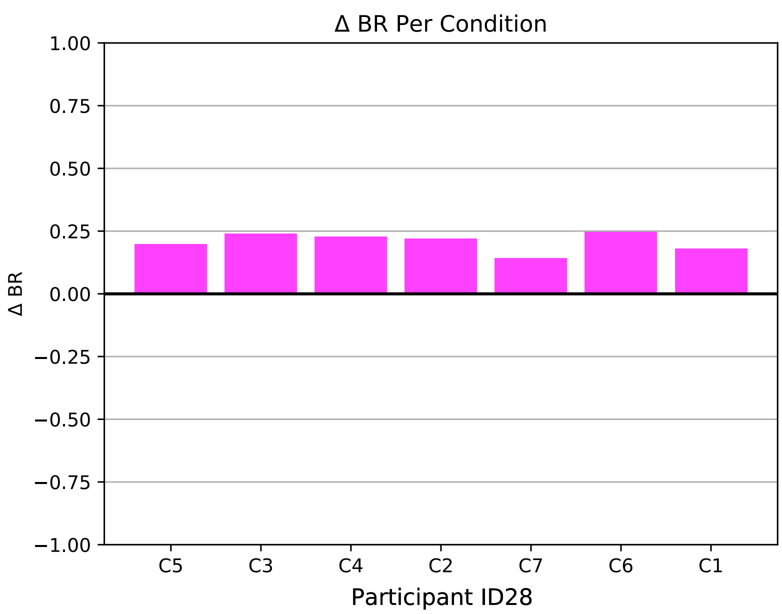
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.





ID 28 REGULAR GROUP





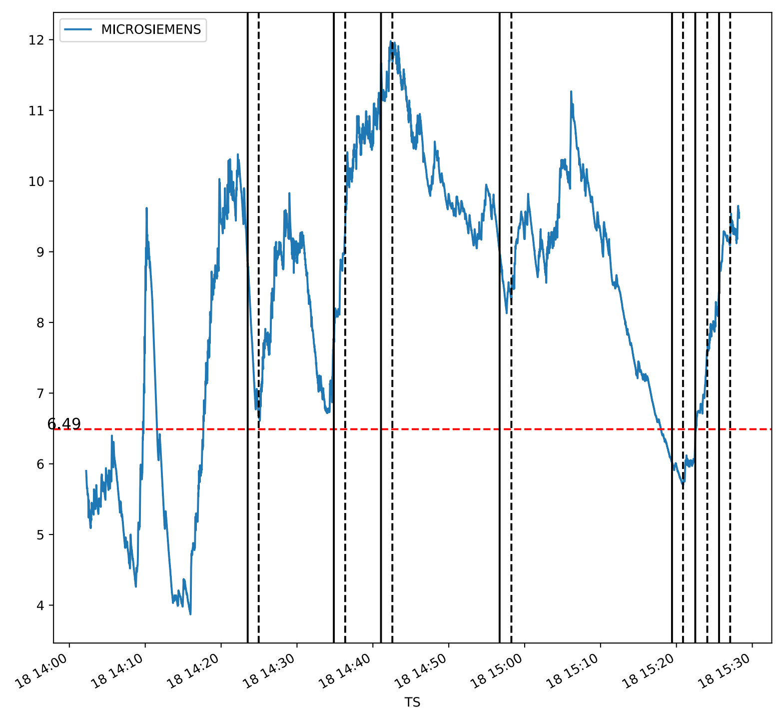
The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

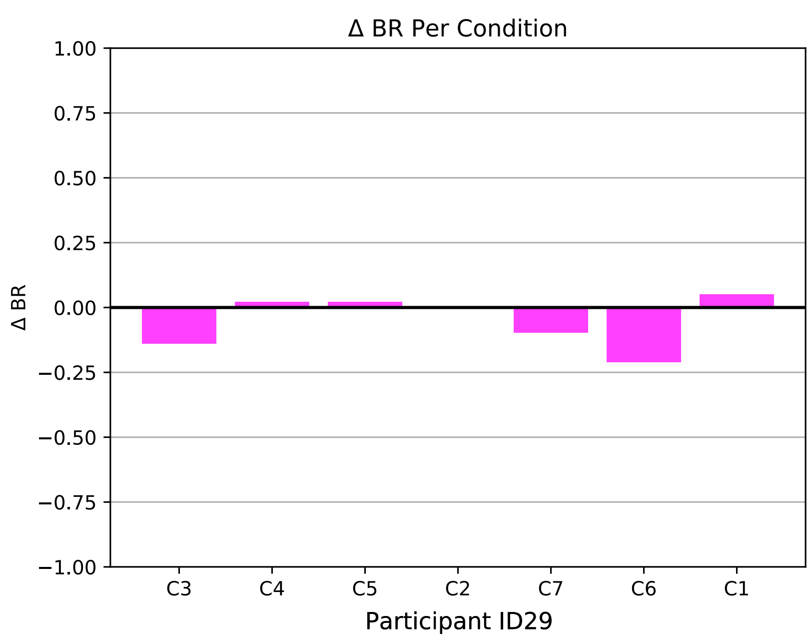
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

ID 29 REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.



The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.



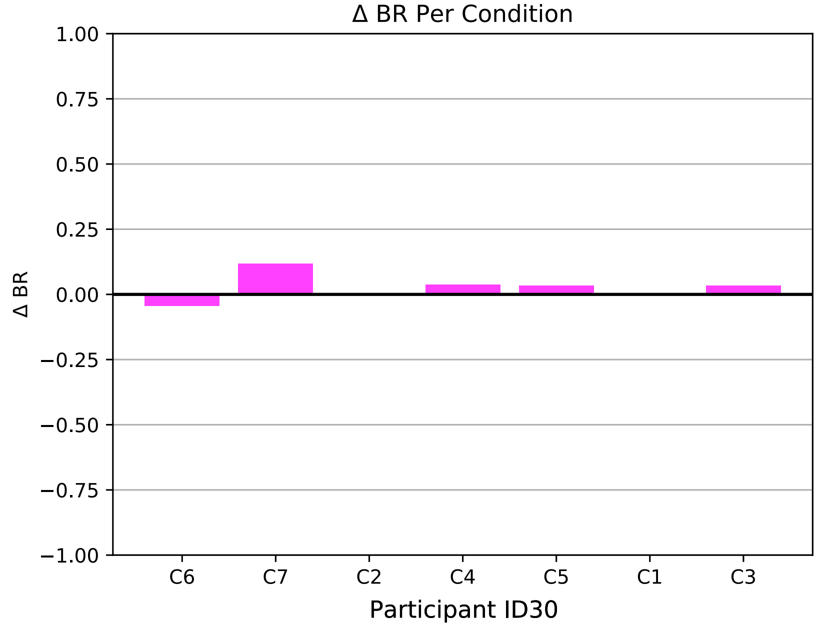
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

ID 30
FAST
GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

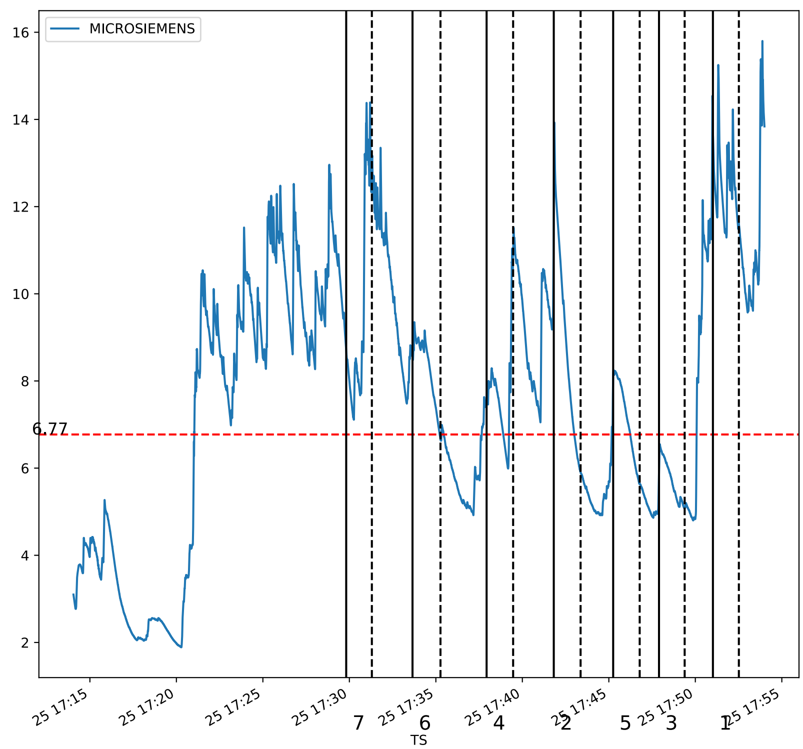


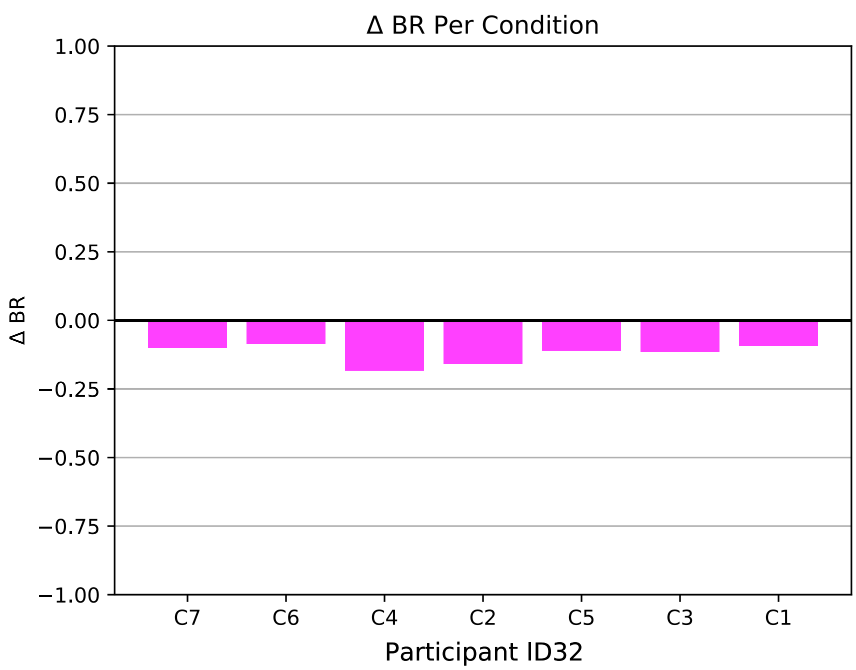
ID 32
SLOW GROUP

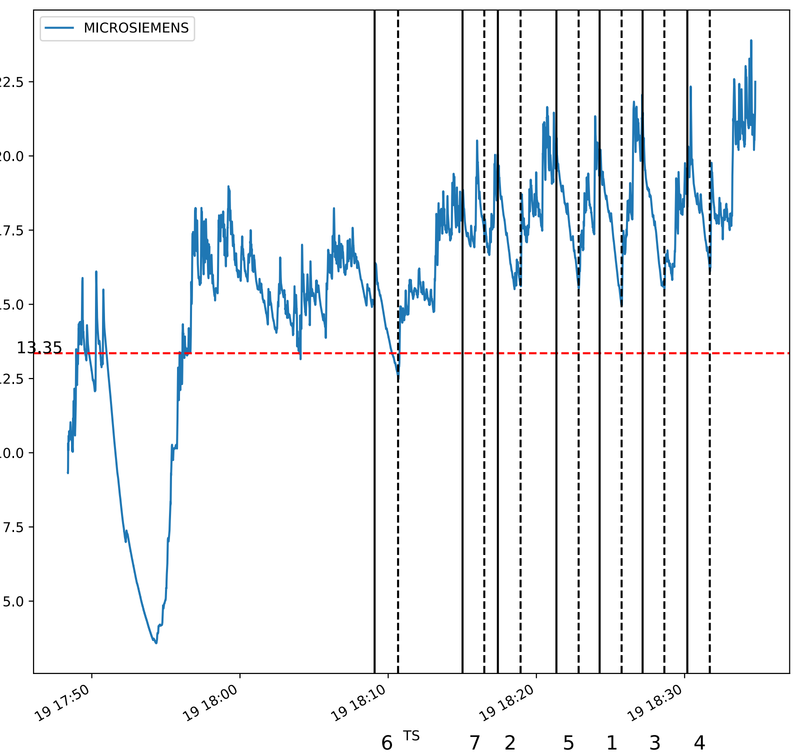
The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

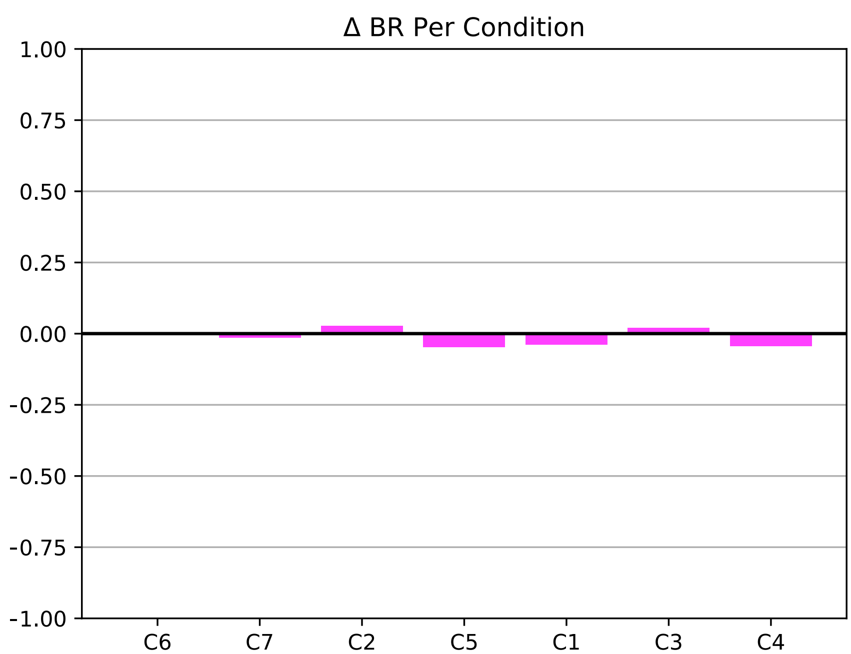
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.









ID 33 FAST GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

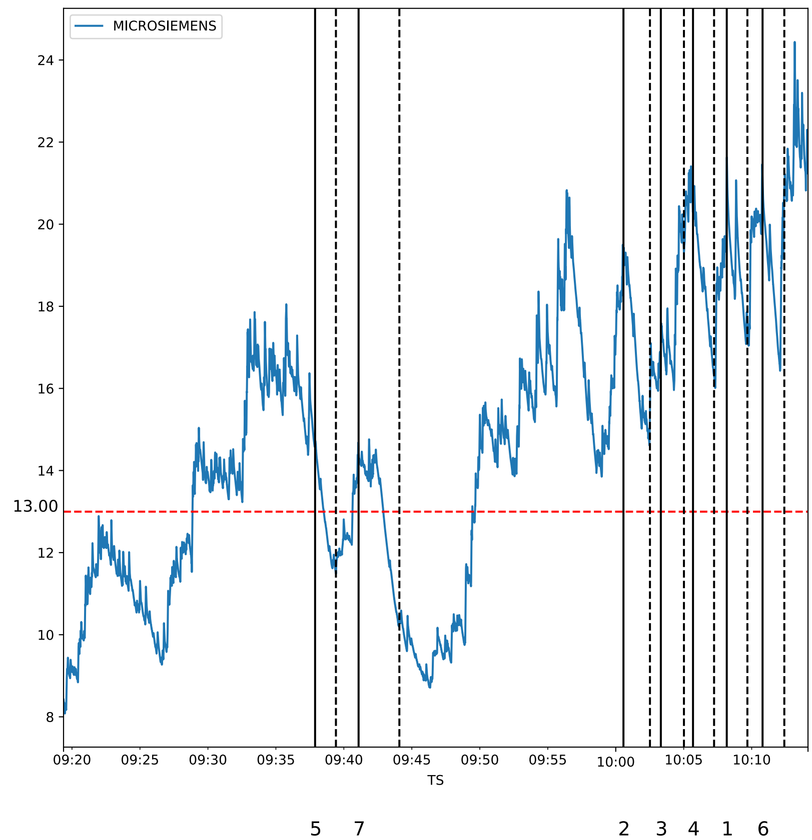
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

ID 34
SLOW
GROUP

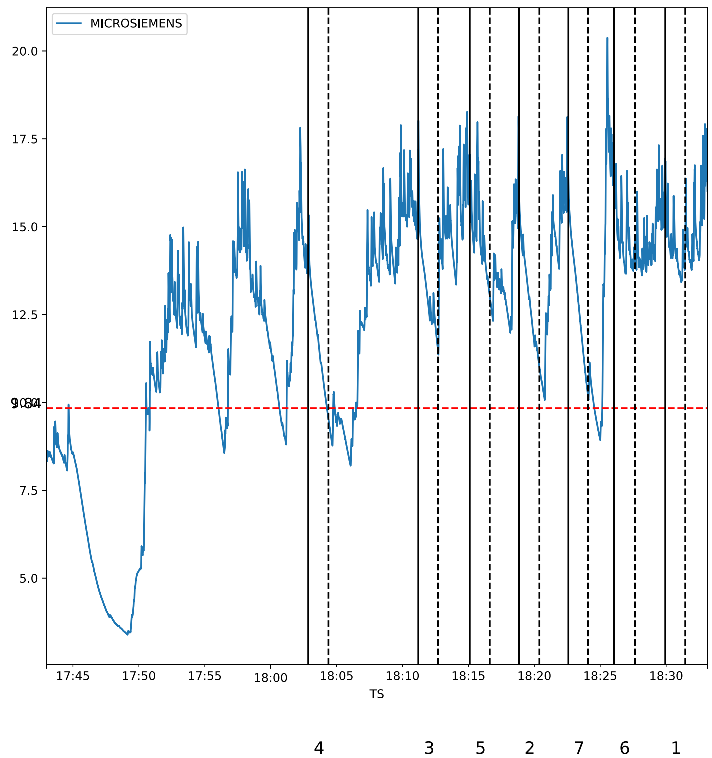
The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

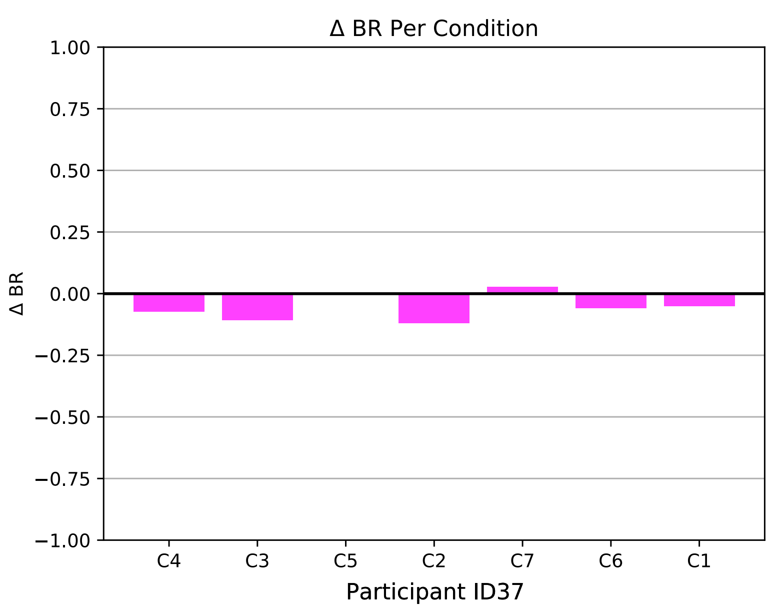
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.



ID 37
FAST
GROUP





The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

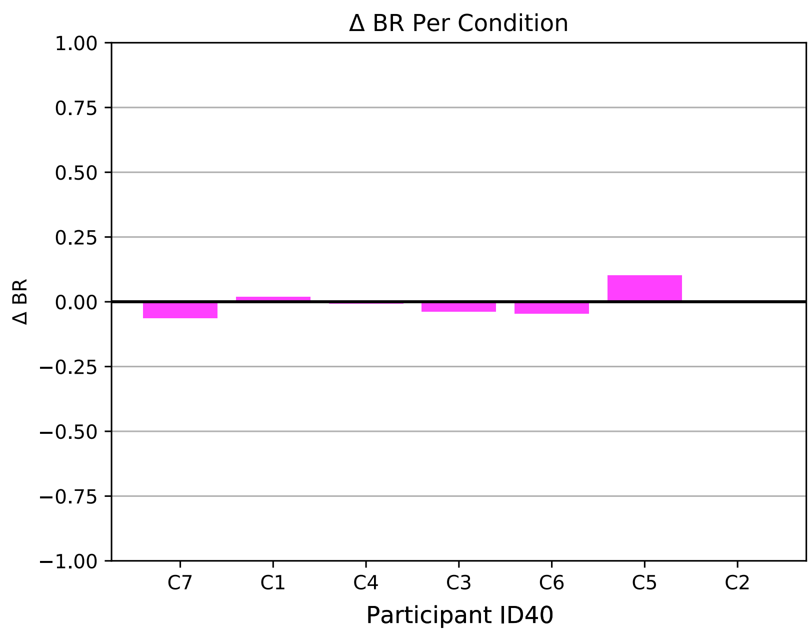
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

ID 40
SLOW
GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

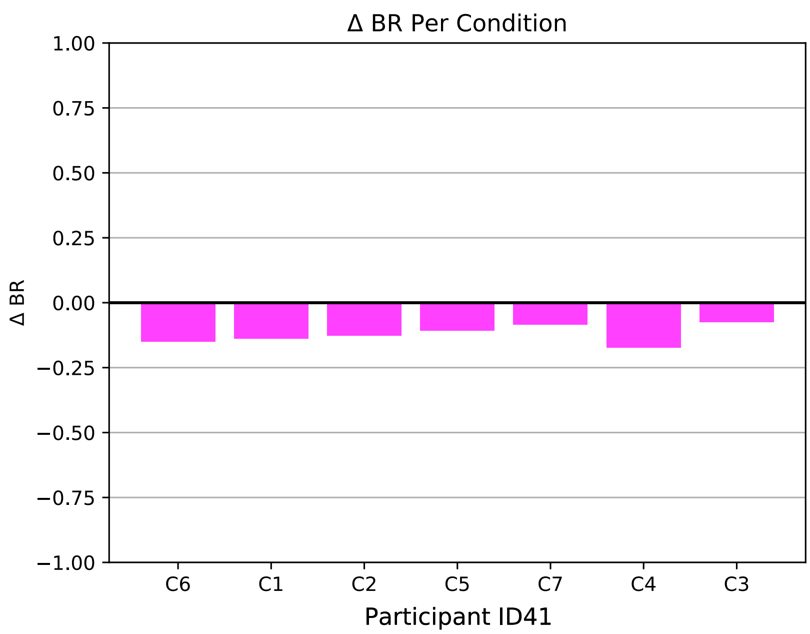


ID 41 SLOW GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

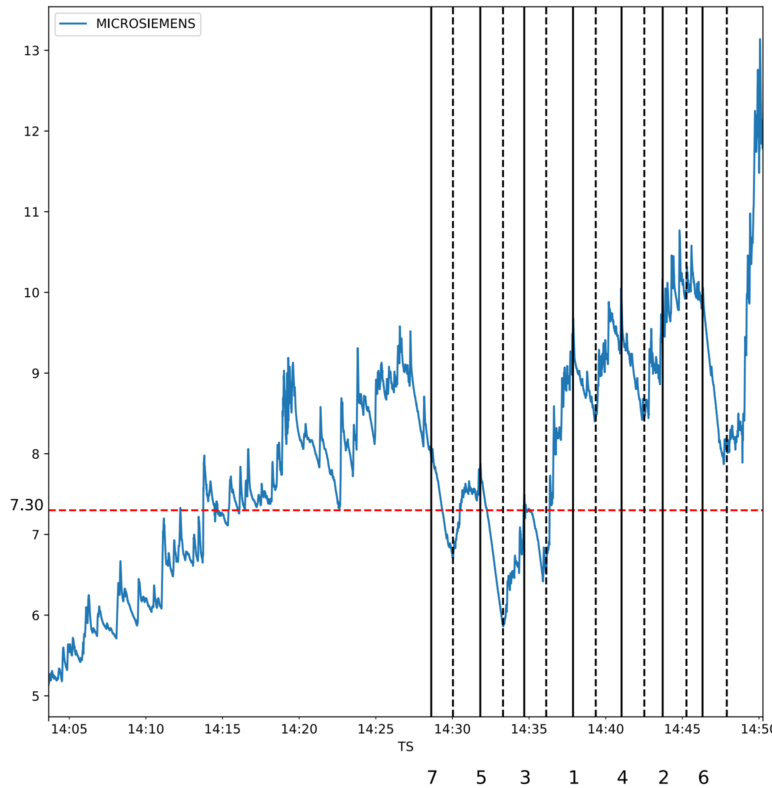


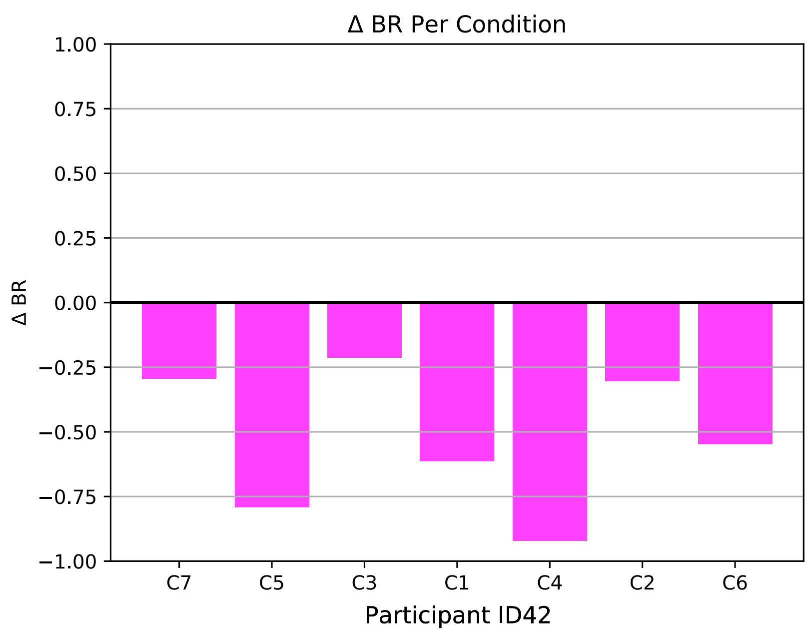
ID 42 REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

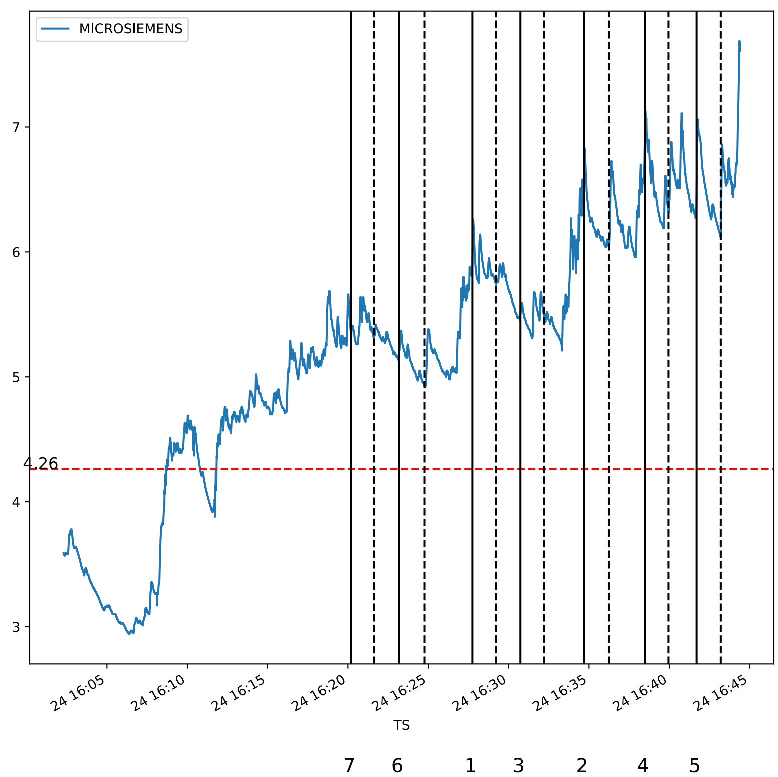
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

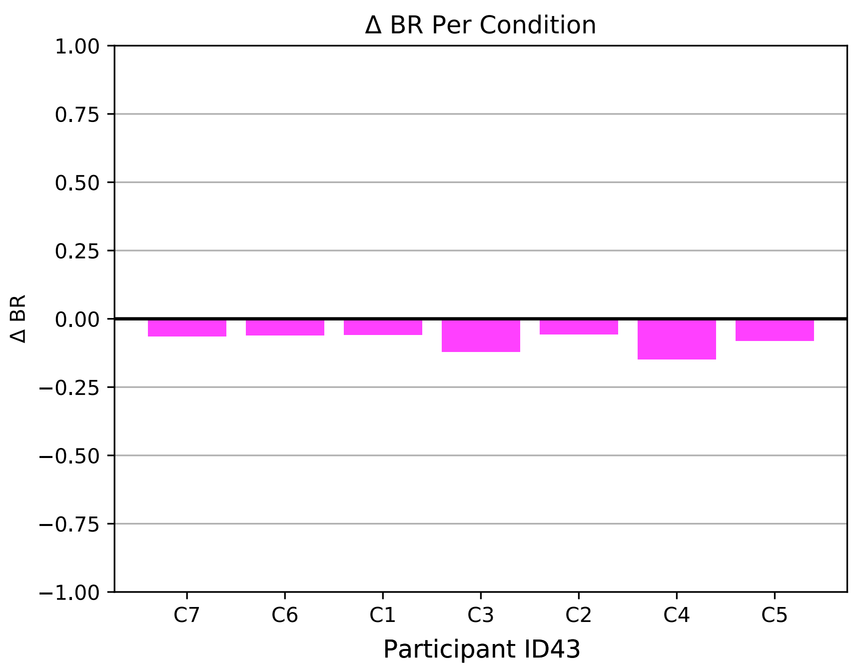
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.





ID 43 SLOW GROUP





The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

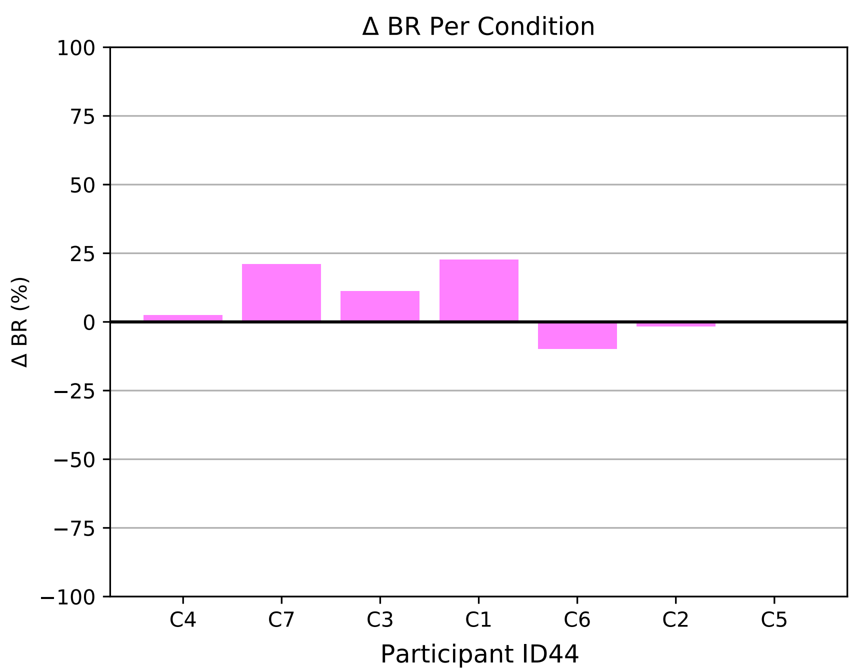
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

ID 44
FAST
GROUP

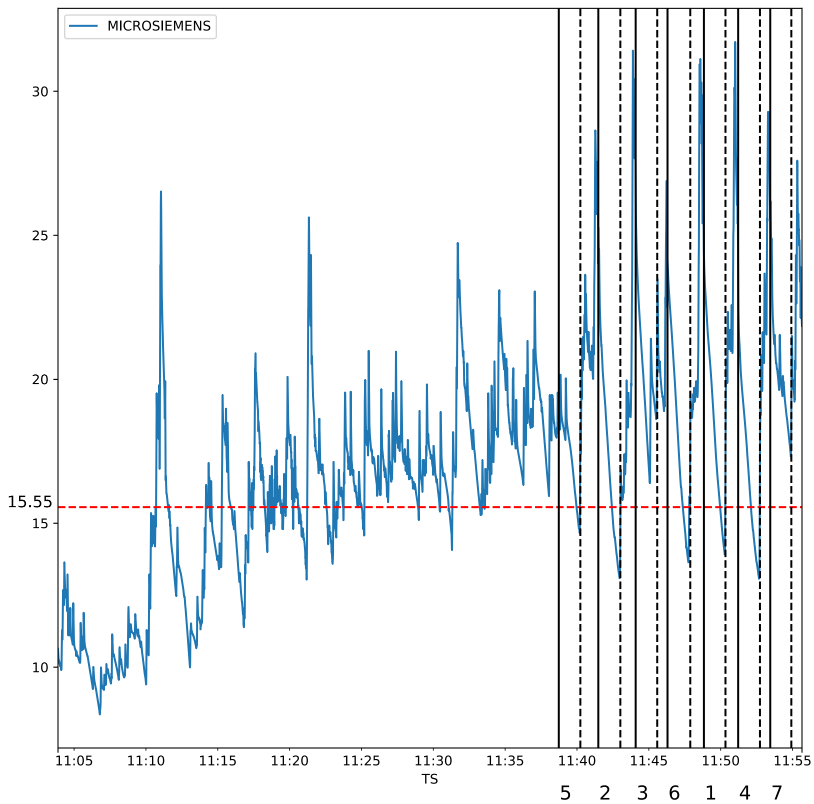
The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

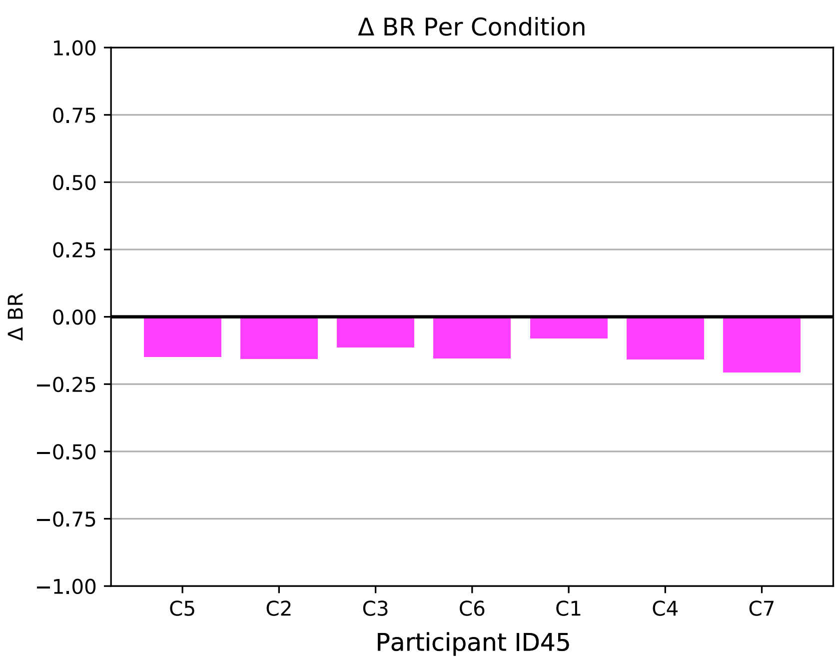
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.



ID 45
FAST
GROUP





The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

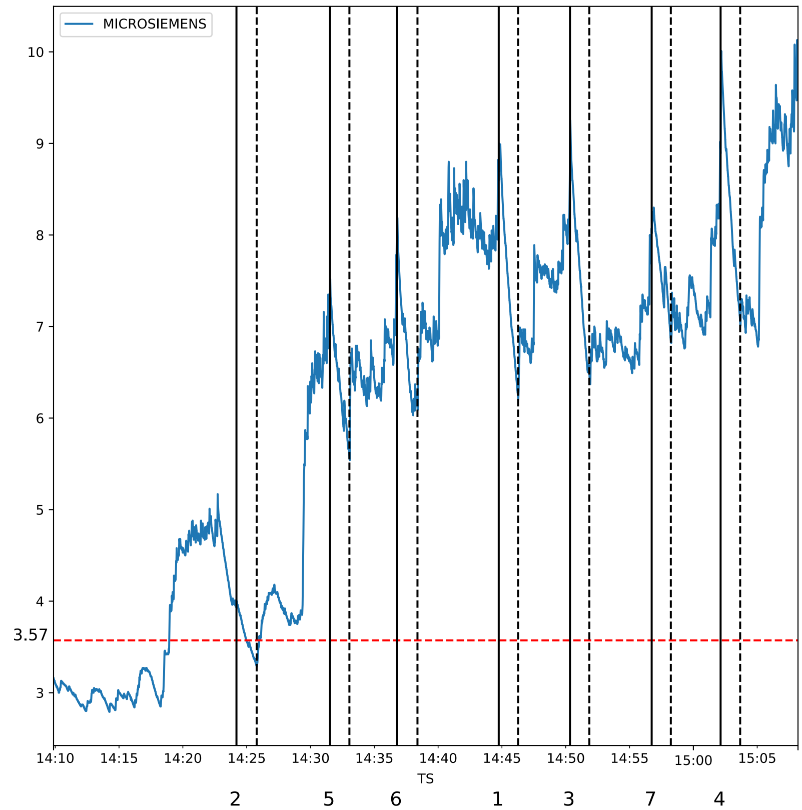
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

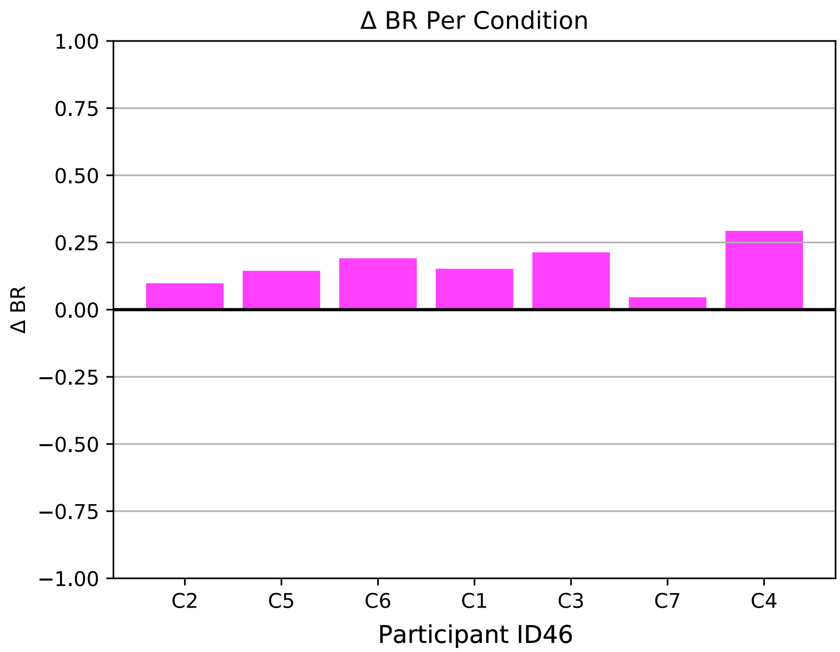
ID 46
FAST
GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

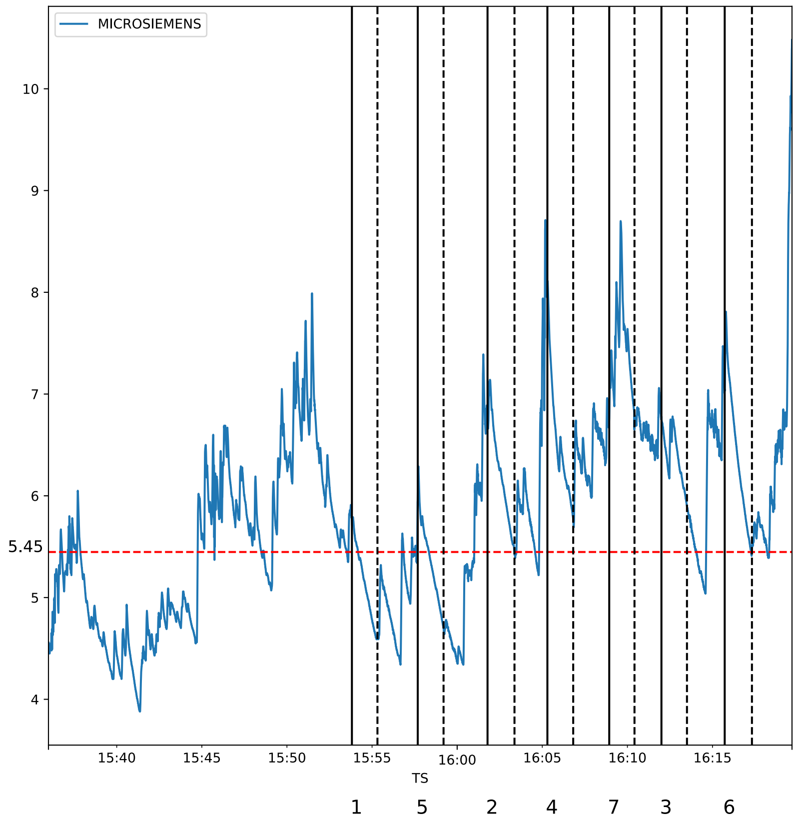
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.





ID 47
FAST GROUP



The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

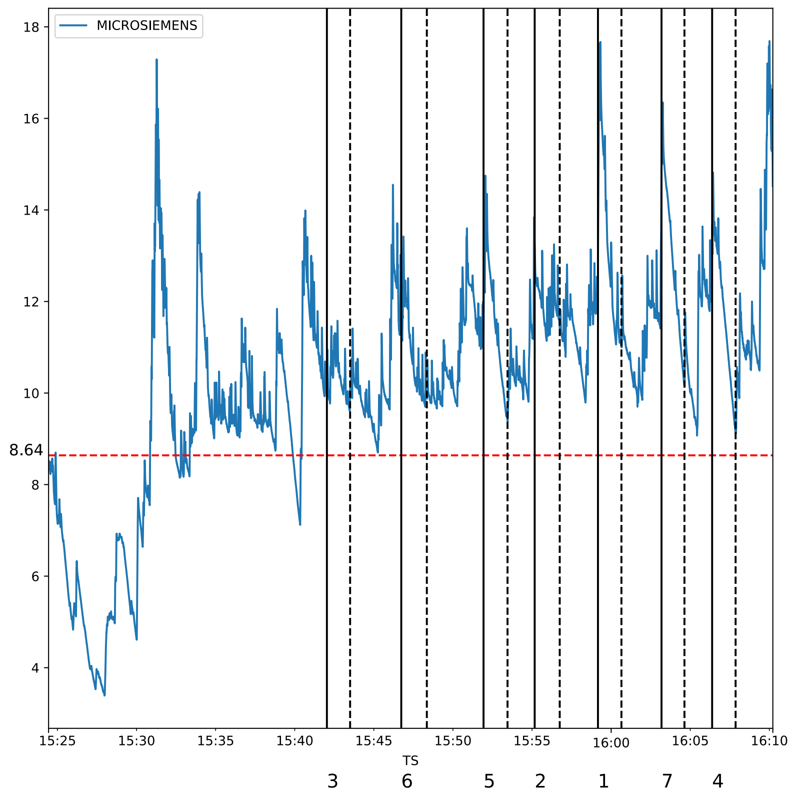
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

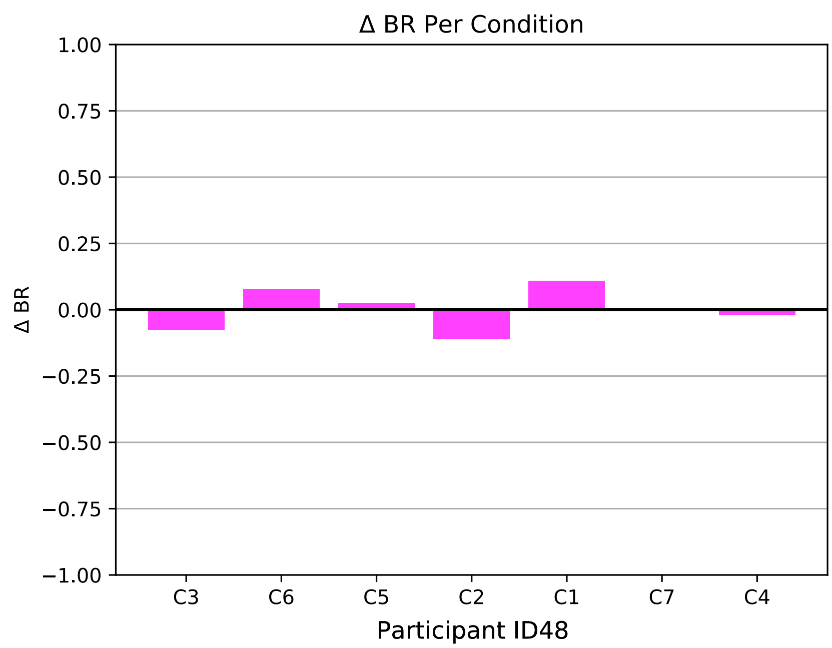
ID 48
SLOW GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

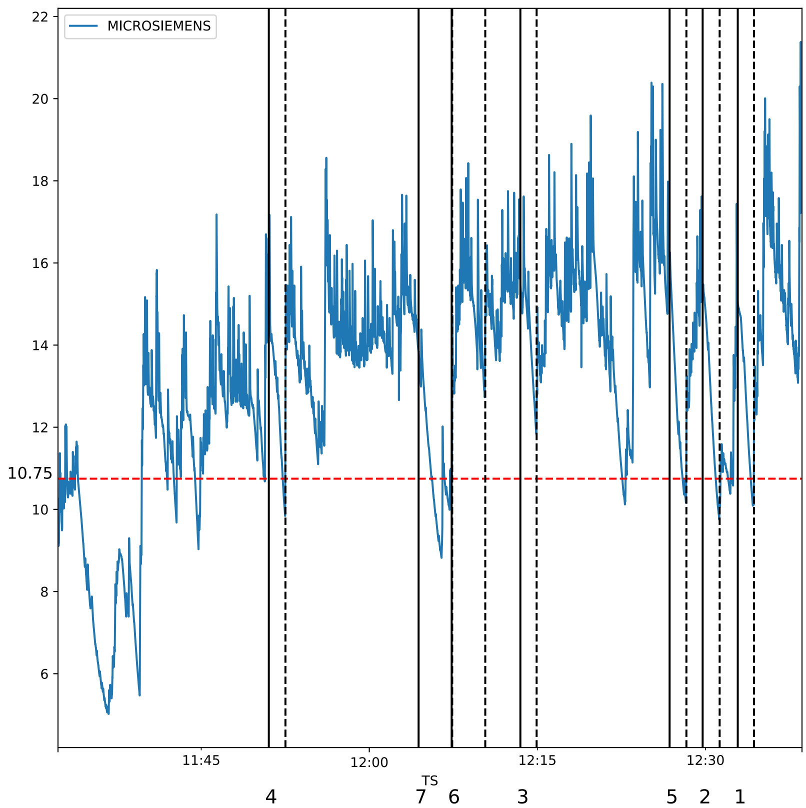
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

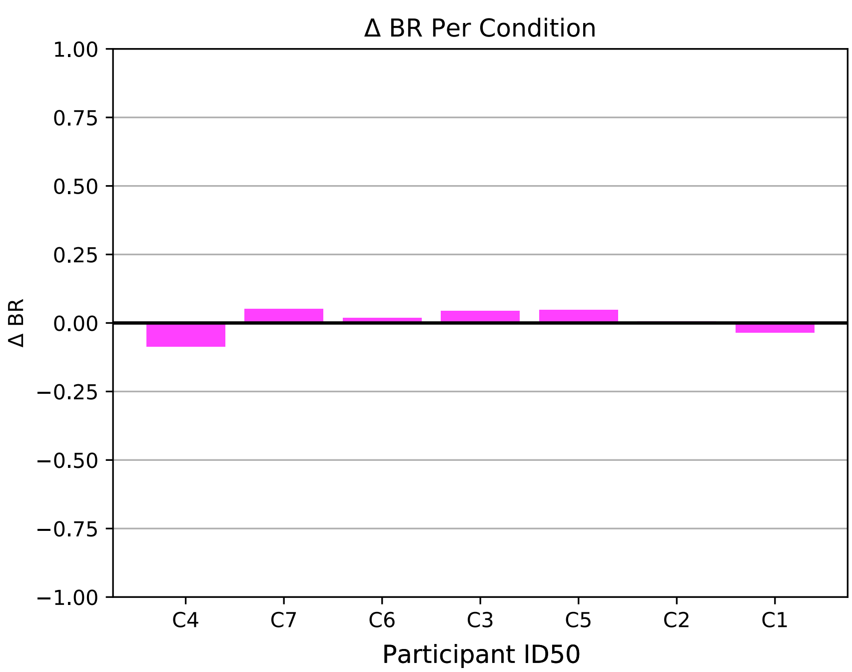
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.





ID 50 SLOW GROUP





The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

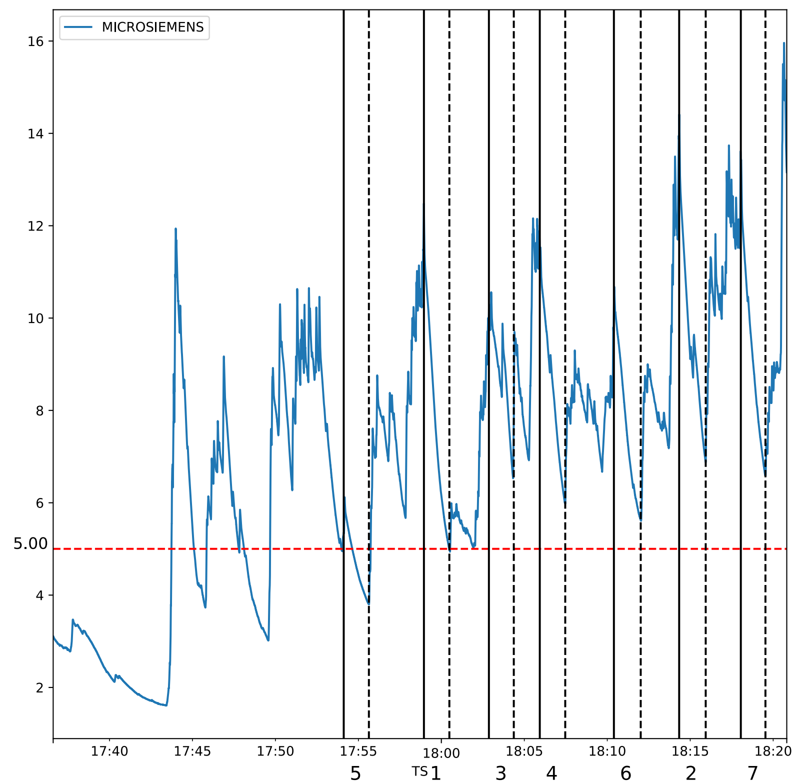
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

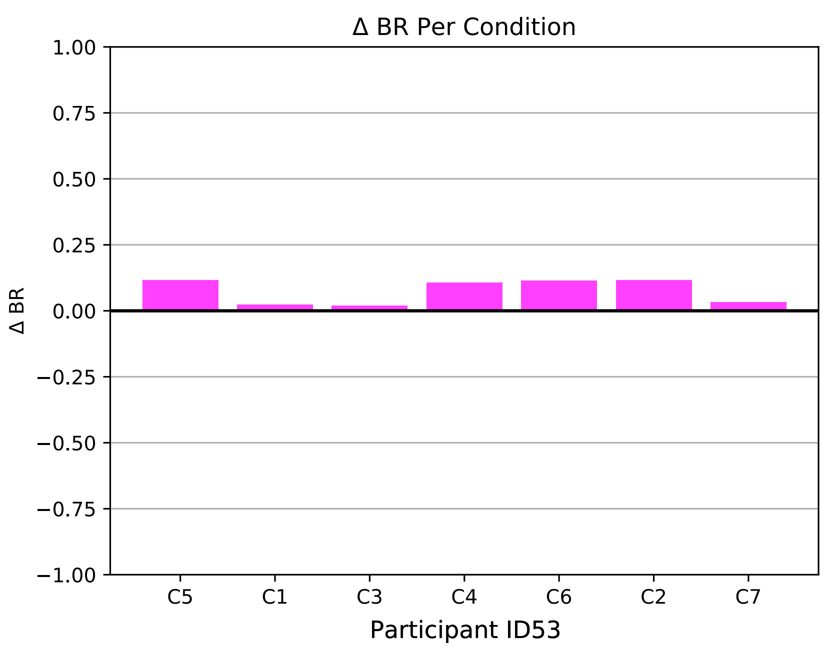
ID 53
SLOW
GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.



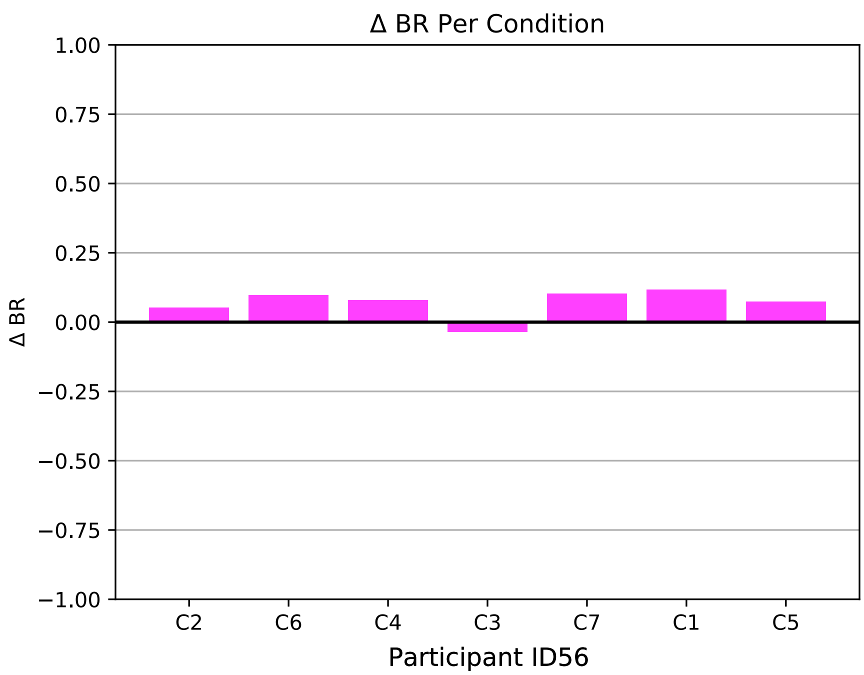


ID 56 REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

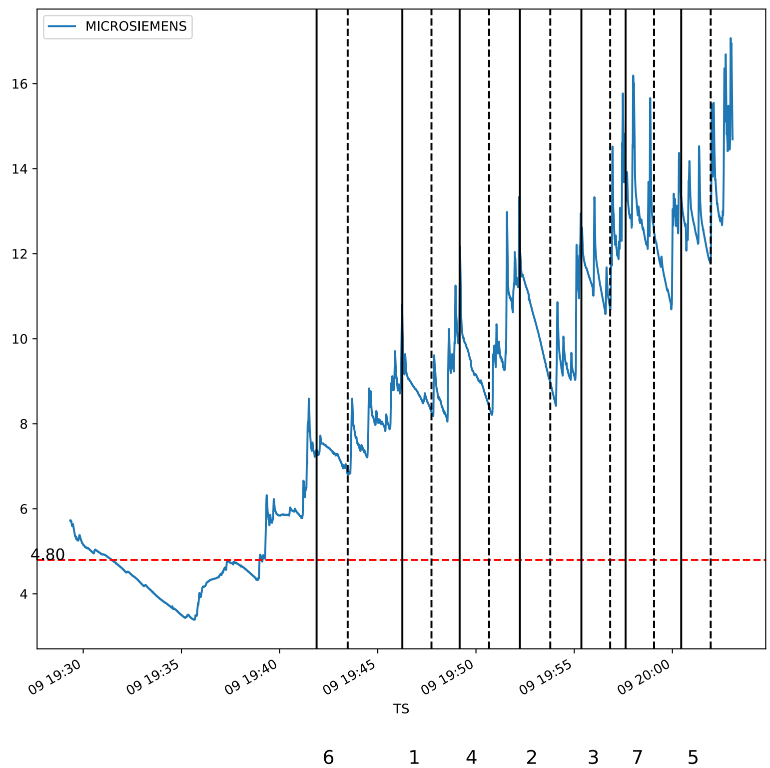


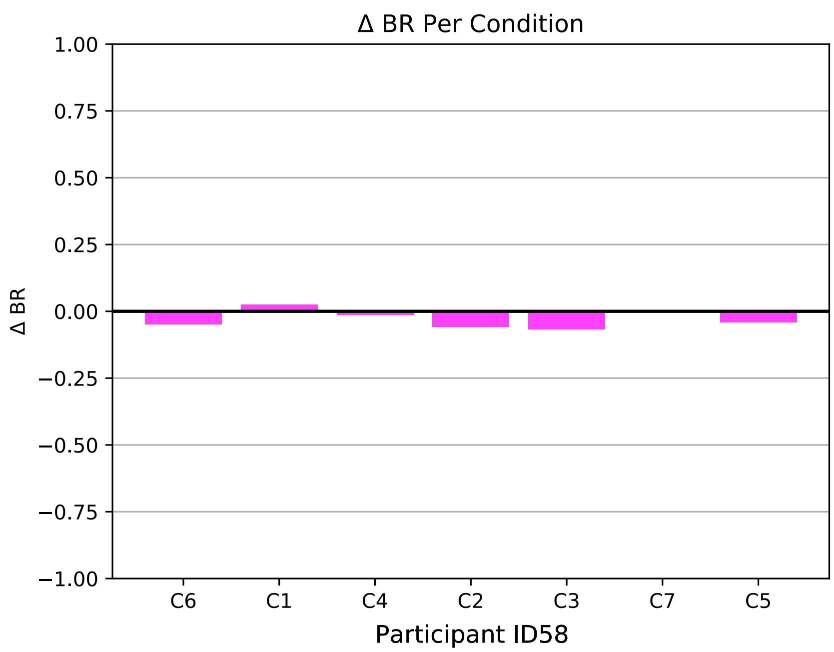
ID 58
REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

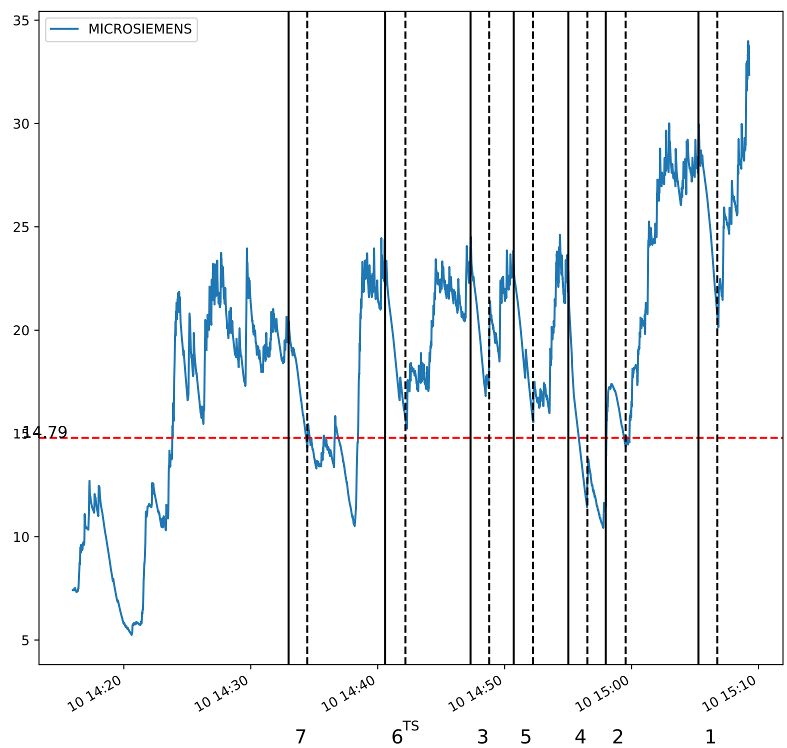
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

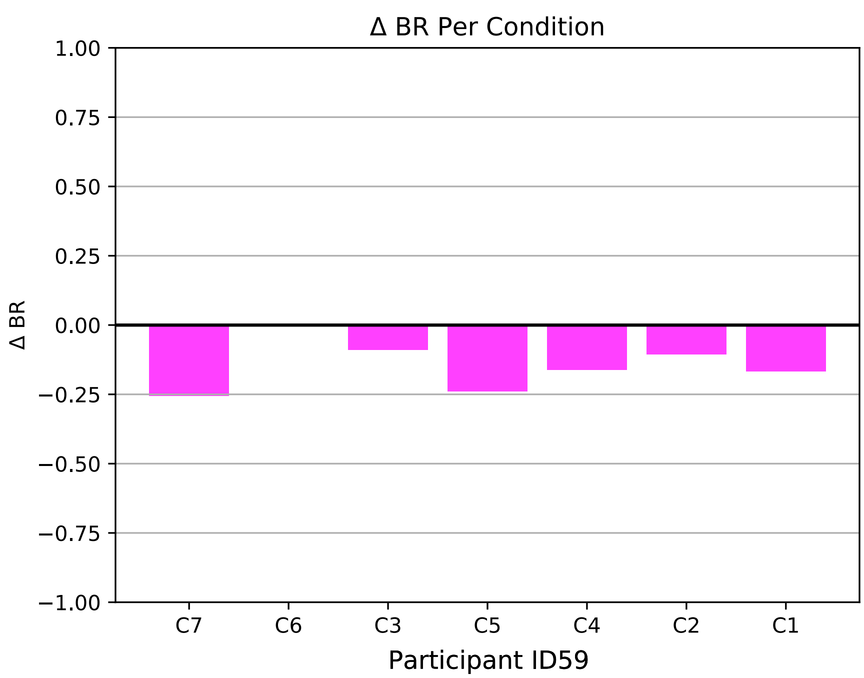
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.





ID 59 REGULAR GROUP





The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

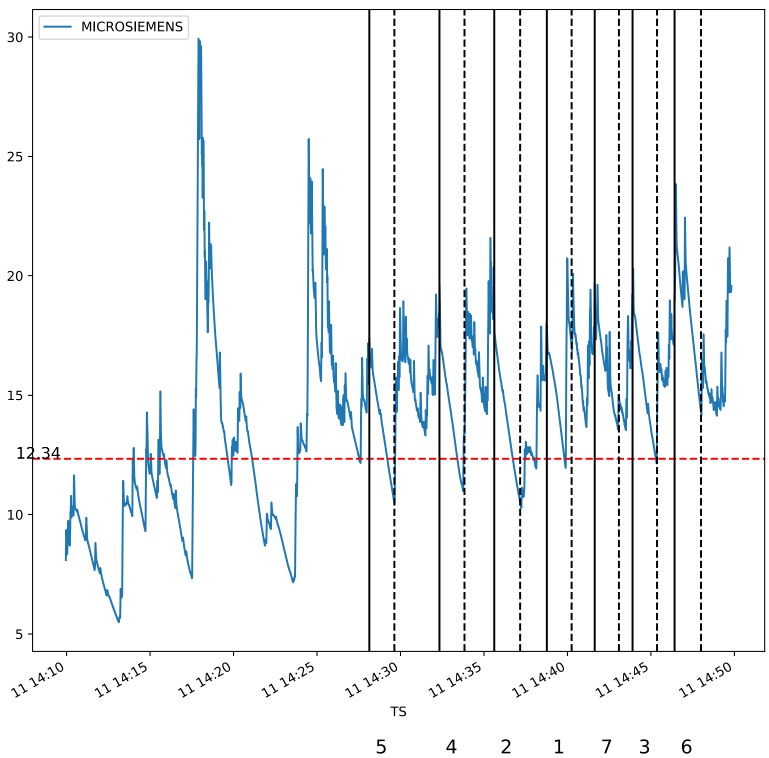
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

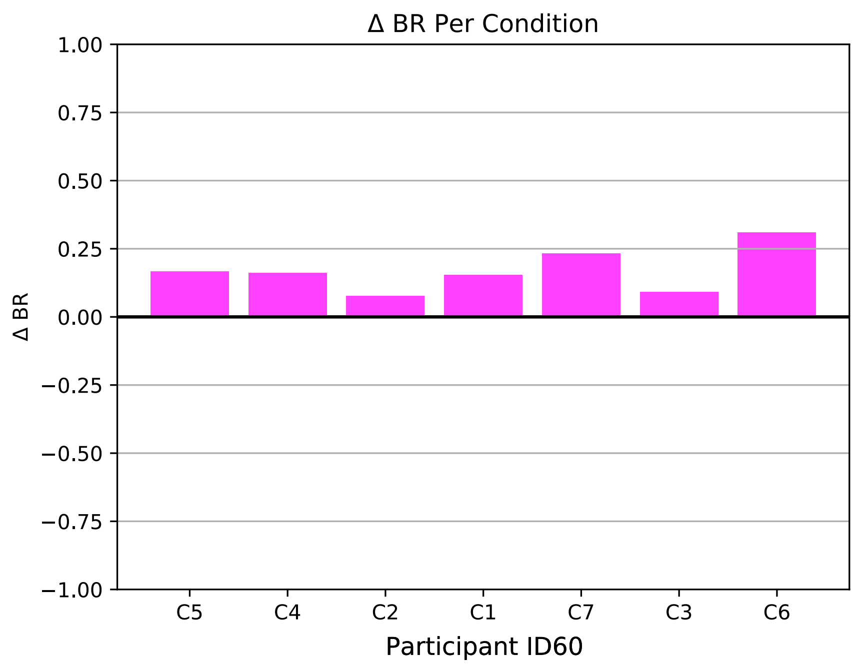
ID 60
FAST GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.



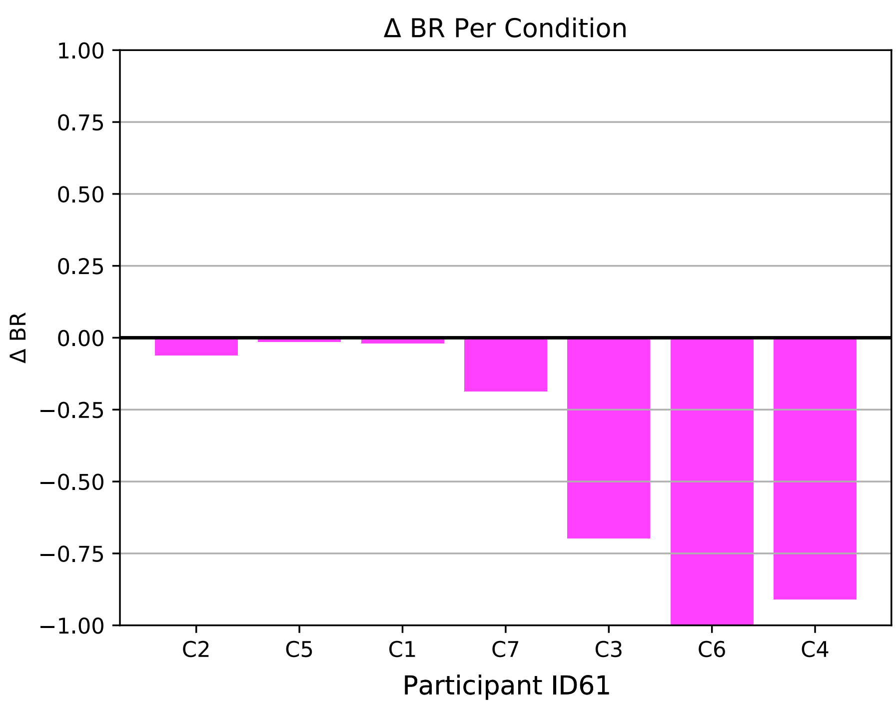


ID 61
FAST
GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

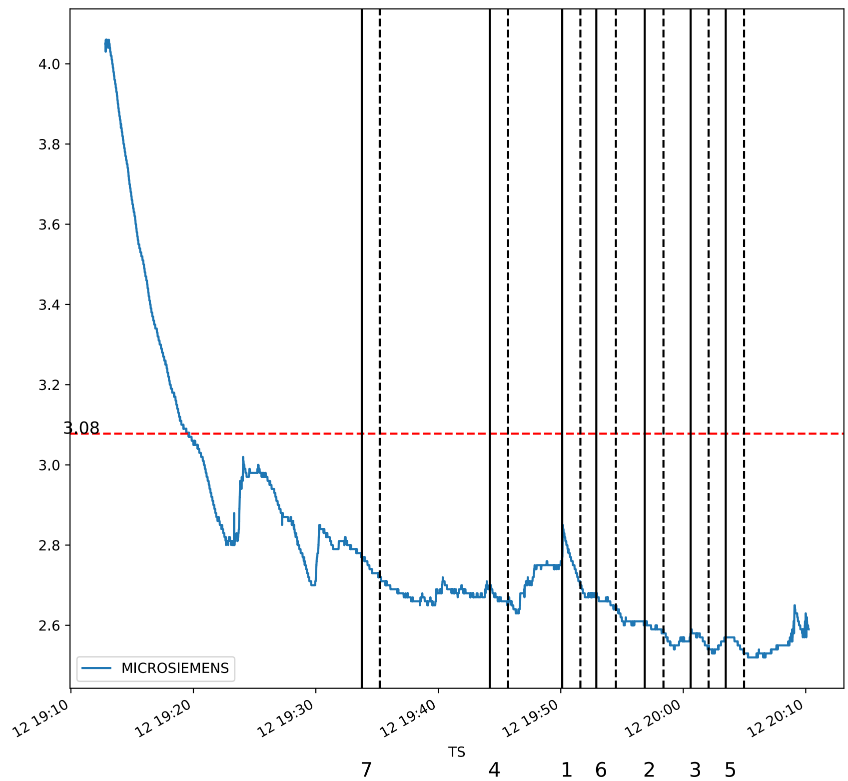


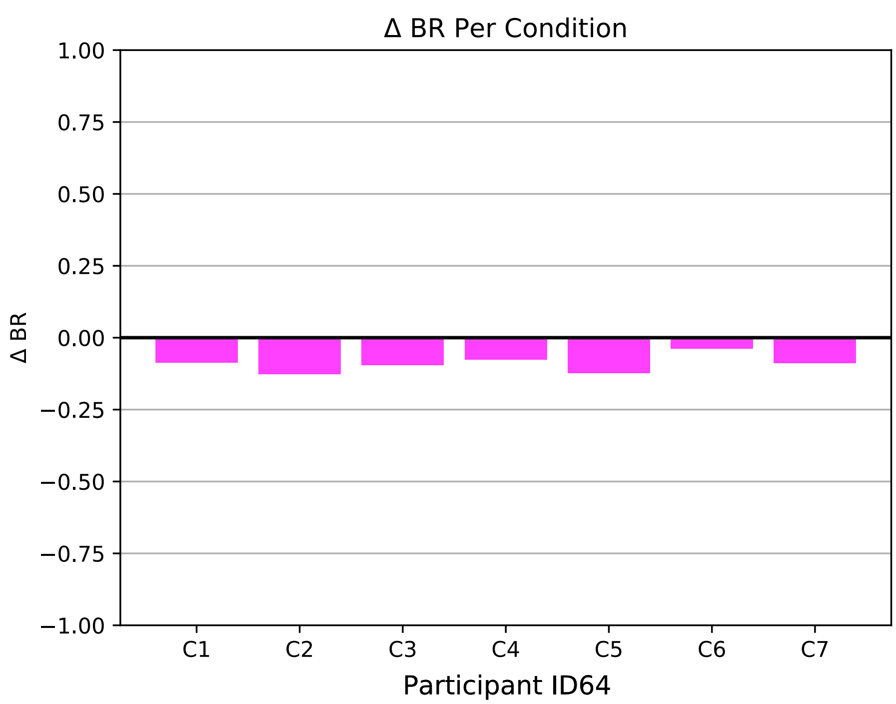
ID 64 REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

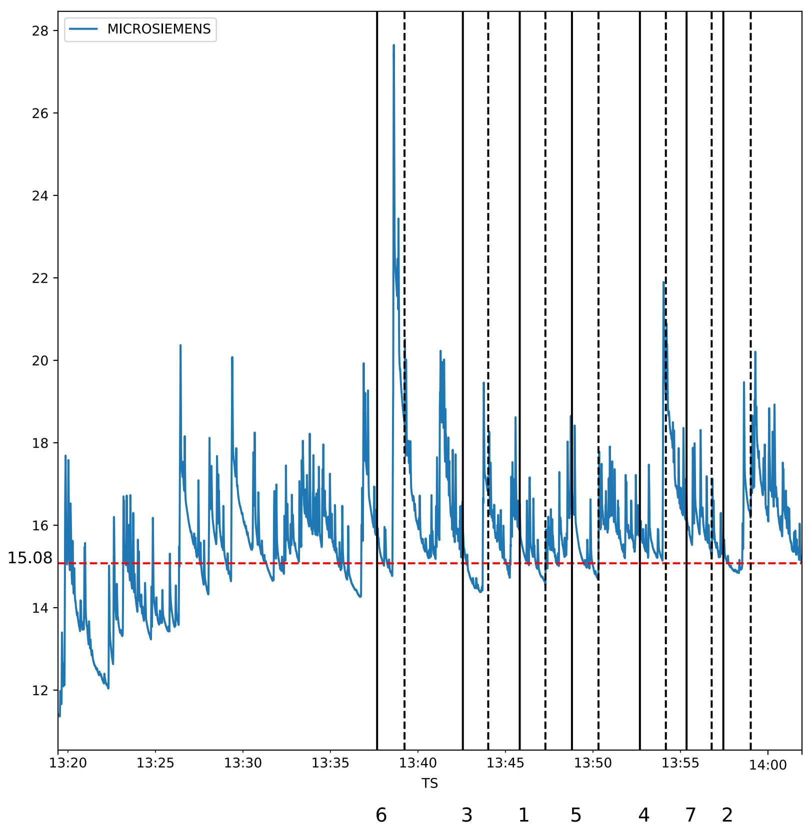
The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

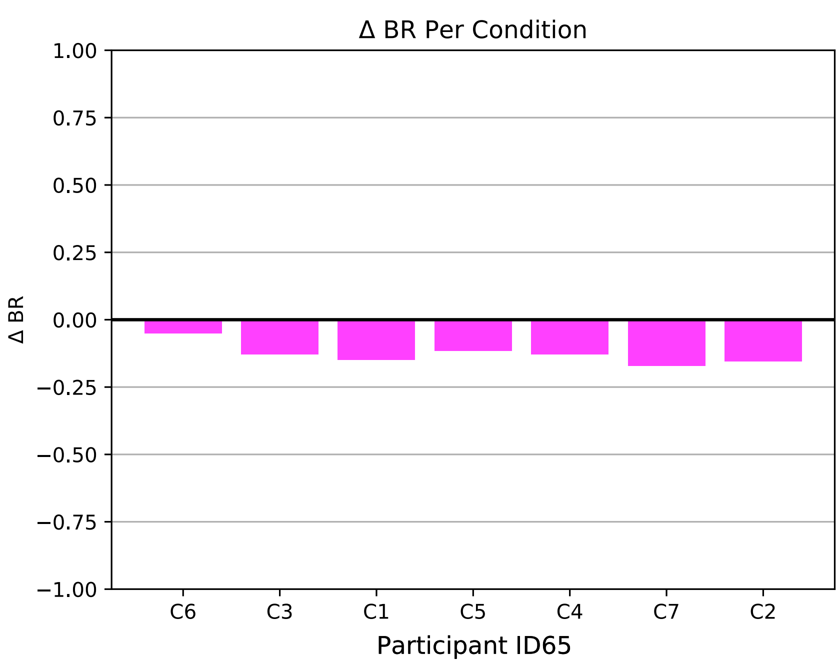
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.





ID 65
SLOW GROUP





The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

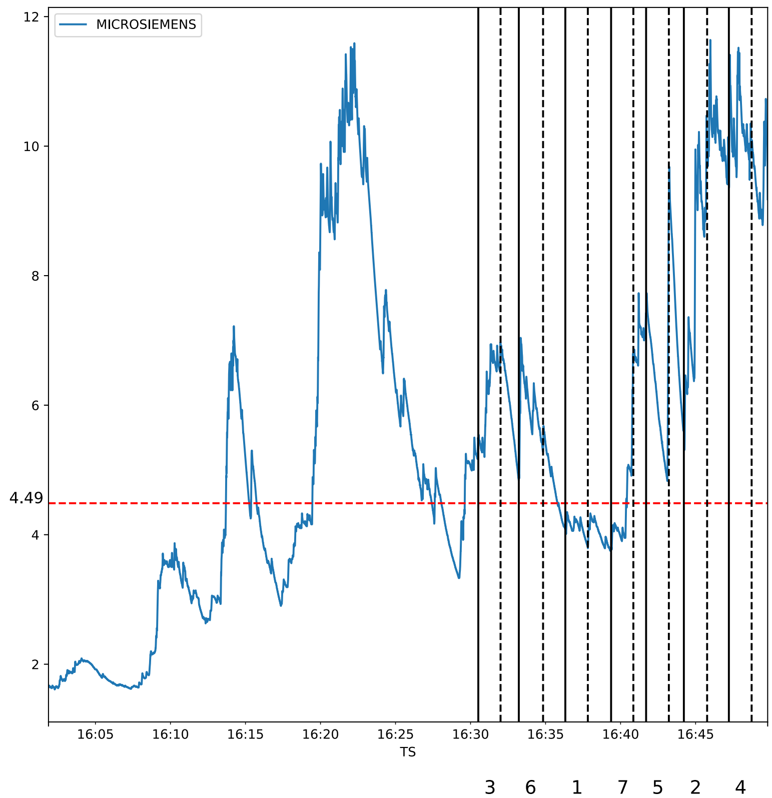
Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.

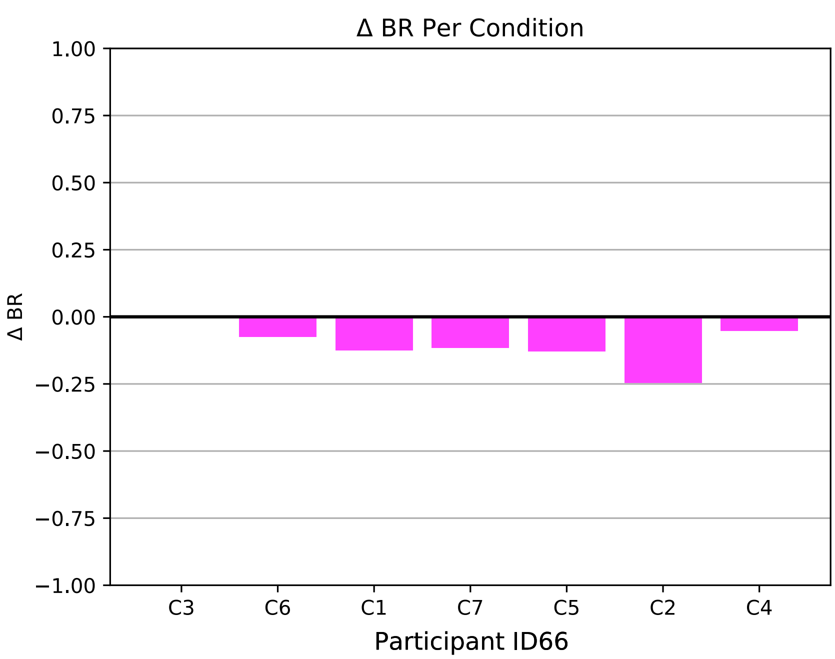
ID 66 REGULAR GROUP

The line graphs show the electrodermal activity (raw signal) of the participant througout the process starting with the baseline. Each vertical line of the plot signifies the start of a testing condition and each dotted vertical line the end of a testing condition and beginning of UI survey. The time is noted at the bottom. The number of the corresponding condition (as conditions are randomized) is also noted at the bottom. The red horizontal line stands for the baseline average.

The bar graphs show the change in breathng rate (BR) from baseline for each condition in the randomized sequence.

Each page corresponds to one anonymous participant. If a line graph or bar graph are missing it means that the corresponding data were discarded, usually due to bad sensor connectivity.





7. BIBLIOGRAPHY

- Aaron et al., (2015) Soft robotic actuators utilizing asymmetric surfaces. US patent. WO2015191585A1

- Addison, P. S., Watson, J. N., Mestek, M. L., Ochs, J. P., Uribe, A. A., & Bergese, S. D. (2015). Pulse oximetry-derived respiratory rate in general care floor patients. Journal of clinical monitoring and computing, 29(1), 113–120. https://doi.org/10.1007/s10877-014-9575-5

- Ainley, V., Brass, M., & Tsakiris, M. (2014). Heartfelt imitation: High interoceptive awareness is linked to greater automatic imitation. Neuropsychologia, 60, 21-28.

- Aldahan, A. S., Shah, V. V., Mlacker, S., & Nouri, K. (2016). Sun Exposure in History. JAMA dermatology, 152(8), 896. https://doi.org/10.1001/jamadermatol.2015.5660

- Althoefer, K. (2018) Antagonistic actuation and stiffness control in soft inflatable robots. Nat Rev Mater 3, 76–77. https://doi.org/10.1038/s41578-018-0004-0

- Andres, K., Bellwald, L., & Brenner, H. D. (1993). Empirische Untersuchung einer leiborientierten Therapie mit schizophrenen Patienten [Empirical study of a physically oriented therapy with schizophrenic patients]. Zeitschrift fur klinische Psychologie, Psychopathologie und Psychotherapie, 41(2), 159–169.

- Arafsha, F., Alam, K. M., & AbduEl Saddik, A. (2012). EmoJacket: Consumer centric wearable affective jacket to enhance emotional immersion. In Innovations in Information Technology (IIT), 2012 International Conference on. IEEE, 350--355

- Aristotle (1986). *De Anima* (Lawson-Tancred, H., Trans.) Penguin (Originally published ca. 350 B.C.E)

- Aristotle (2018). *The Art of Rhetoric* (Waterfield, R., Trans.) Oxford University Press (Originally published ca. 367-322 B.C.E)

- Ashby, W. R. (1956). *An Introduction to Cybernetics.* John Wiley & Sons.

- Ashby, W. R. (1960). D*esign for a brain: The origin of adaptive behavior* (2nd ed.) John Wiley & Sons. (Originally published in 1952)

- Ayres A. J. (1972). *Sensory Integration and Learning Disorders*. Western Psychological Services.

- Bar-Cohen, Y (2002). Electroactive Polymers as Artificial Muscles: A Review, Journal of Spacecraft and Rockets. 39 (6), 822-827.

- Barrett, L. F. (2004). Feelings or words? Understanding the content in self-report ratings of experienced emotion. Journal of Personality and Social Psychology, 87, 266–281.

- Barrett, L. F. (2017). *How emotions are made: The secret life of the brain.* Houghton Mifflin Harcourt

- Barrett, L. F., Gross, J., Christensen, T. C., & Benvenuto, M. (2001). Knowing what you're feeling and knowing what to do about it: Mapping the relation between emotion differentiation and emotion regulation. Cognition & Emotion, 15, 713–724.

- Bavelas, J. B., Black, A., Chovil, N., Lemery, C. R., & Mullett, J. (1988). Form and function in motor mimicry: Topographic evidence that the primary function is communicative. Human Communication Research, 14(3), 275–299. https://doi.org/10.1111/j.1468-2958.1988.tb00158.x

- Belforte, G., Eula, G., Ivanov, A., & Sirolli, S. (2014). Soft Pneumatic Actuators for Rehabilitation. Actuators, 3(2), 84-106. doi:10.3390/act3020084

- Berger, G. E., Burnett, P., & McGorry, P. D. (2008). Pilot study evaluating the effect of massage therapy on stress, anxiety and aggression in a young adult psychiatric inpatient unit. The Australian and New Zealand journal of psychiatry, 42(5), 414–422. https://doi.org/10.1080/00048670801961131

- Bestbier, L., & Williams, T. I. (2017). The Immediate Effects of Deep Pressure on Young People with Autism and Severe Intellectual Difficulties: Demonstrating Individual Differences. Occupational therapy international, 2017, 7534972. https://doi.org/10.1155/2017/7534972

- Bluedorn, A. C. (2002). *The Human Organization of Time: Temporal realities and experience.* Stanford University Press.

- Blume, C., Garbazza, C., & Spitschan, M. (2019). Effects of light on human circadian rhythms, sleep and mood. Somnologie : Schlafforschung und Schlafmedizin [Somnology : sleep research and sleep medicine], 23(3), 147–156. https://doi.org/10.1007/s11818-019-00215-x

- Bratman, G. N., Hamilton, J. P., Hahn, K. S., Daily, G. C., & Gross, J. J. (2015). Nature experience reduces rumination and subgenual prefrontal cortex activation. Proceedings of the National Academy of Sciences, 112(28), 8567–8572. https://doi.org/10.1073/pnas.1510459112

- Brener, J., & Ring, C. (2016). Towards a psychophysics of interoceptive processes: The measurement of heartbeat detection. Philosophical Transactions of the Royal Society B: Biological Sciences, 371(1708), 20160015. https://doi:10.1098/rstb.2016.0015

- Brinck I. (2018). Empathy, engagement, entrainment: the interaction dynamics of aesthetic experience. Cognitive Processing, 19(2), 201–213. https://doi.org/10.1007/s10339-017-0805-x

- Bumatay A., Seo J.H.: Investigating the Role of Biofeedback and Haptic Stimulation in Mobile Paced Breathing Tools. In: Schmorrow D., Fidopiastis C. (eds) Augmented Cognition. Neurocognition and Machine Learning. AC 2017. Lecture Notes in Computer Science, vol 10284. Springer, Cham (2017).

- Busboom, D. & Schwaiblmair, F, (2016). Psychotherapy with mentally disabled persons: the importance of non-verbal qualities in music therapy with adults with severe autism. Nordic Journal of Music Therapy, 25. 123-123. 10.1080/08098131.2016.1180148.

- Cacioppo J. T., & Berntson G. G. (1994). Relationship between attitudes and evaluative space: A critical review, with emphasis on the separability of positive and negative substrates. Psychological Bulletin, 115, 401–423.

- Canales-Johnson, A., Silva, C., Huepe, D., Rivera-Rei, A., Noreika, V., Del Carmen Garcia, M., Silva, W…. Bekinschtein T. A. (2015): Auditory Feedback Differentially Modulates Behavioral and Neural Markers of Objective and Subjective Performance When Tapping to Your Heartbeat. Cerebral Cortex 25, 11: 4490–4503

- Cappello, L., Galloway, K.C., Sanan, S., Wagner, D., Granberry, R., Engelhardt, S., Haufe, F.L., Peisner, J.D., & Walsh, C.J. (2018). Exploiting Textile Mechanical Anisotropy for Fabric-Based Pneumatic Actuators. Soft robotics, 5 5, 662-674 .

- Carr L, Iacoboni M, Dubeau MC, Mazziotta JC, Lenzi GL. 2003 Neural mechanisms of empathy in humans: a relay from neural systems for imitation to limbic areas. Proceedings of the National Academy of Sciences of America 100, 5497 – 5502. https://doi.org/10.1073/pnas.0935845100

- Carr, L., Iacoboni, M., Dubeau, M. C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: a relay from neural systems for imitation to limbic areas. Proceedings of the National Academy of Sciences of the United States of America, 100(9), 5497–5502.

- Chang, A., O'Modhrain, S., Jacob, R., Gunther, E., Ishii, H. (2002). ComTouch: design of a vibrotactile communication device. In Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques (DIS '02). Association for Computing Machinery, New York, NY, USA, 312–320. DOI:https://doi.org/10.1145/778712.778755

- Chatel-Goldman, J., Congedo, M., Jutten, C., & Schwartz, J. L. (2014). Touch increases autonomic coupling between romantic partners. Frontiers in behavioral neuroscience, 8, 95. https://doi.org/10.3389/fnbeh.2014.00095

- Chen H. Y., Yang H., Chi H. J., Chen H.-M. (2013). Physiological effects of deep touch pressure on anxiety alleviation: the weighted blanket approach. Journal of Medical and Biological Engineering. 33(5):463–470. doi: 10.5405/jmbe.1043.

- Choi, K. Y., Lee, J., ElHaouij, N., Picard, R., and Ishii. H., (2021). ASpire: Clippable, Mobile Pneumatic-Haptic Device for Breathing Rate Regulation via Personalizable Tactile Feedback. Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, Article 372, 1–8. DOI:https://doi.org/10.1145/3411763.3451602

- Cianchetti, M., Laschi, C., Menciassi, A. et al. (2018) Biomedical applications of soft robotics. Nat Rev Mater 3, 143–153. https://doi.org/10.1038/s41578-018-0022-y

- Clark, A. (2010). *Supersizing the mind: Embodiment, Action, and Cognitive Extension.* Oxford University Press.

- Clark, L. A., & Watson, D. (1991). Tripartite model of anxiety and depression: Psychometric evidence and taxonomic implications. Journal of Abnormal Psychology, 100(3), 316-336. https://doi.org/10.1037//0021-843x.100.3.316

- Clayton, M. Sager, R. and Will, U. (2005). In time with the music: the concept of entrainment and its significance for ethnomusicology. European Meetings in Ethnomusicology, 11, 3–142.

- Clynes, M. (1978). *Sentics: the touch of emotions.* Anchor Press.

- Clynes, M. (1980). The communication of emotion: Theory of sentics. In Plutchick, R., and Kellerman, H. (eds.). *Theories of Emotion.* Academic Press.

- Clynes, M., and Kline, N. (1960). Cyborgs and space. Astronautics 5: 26-27, 74-76

- Cohen, S., (1994) Perceived Stress Scale. MindGarden. https://www.mindgarden.com/documents/PerceivedStressScale.pdf [Download link. Accessed 11022021]

- Cohen, S., Kamarck, T., & Mermelstein, R. (1983). Perceived Stress Scale [Database record]. APA PsycTests. https://doi.org/10.1037/t02889-000

- Condillac, E. (2000) *Treatise on the Sensations.* Clinamen (Originally published 1754)

- Costa, J., Adams, A.T., Jung, M.F., Guimbretière, F., Choudhury, T.: EmotionCheck: leveraging bodily signals and false feedback to regulate our emotions. In: Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp 2016), pp. 758–769 (2016). https://doi.org/10.1145/2971648.2971752

- Craig, A. (2003). Interoception: The sense of the physiological condition of the body. Current Opinion in Neurobiology, 13(4), 500-505. https://doi.org/10.1016/s0959-4388(03)00090-4

- Craig, A. D. (2002). How do you feel? Interoception: The sense of the physiological condition of the body. Nature Reviews Neuroscience, 3(8), 655-666. https://doi.org/10.1038/nrn894

- Critchley, D. H., & Sarah N. Garfinkel., (2017). Interoception and Emotion. Current Opinion in Psychology 17, 7-14. https://doi.org/10.1093/oso/9780198811930.003.0007

- Damasio, A. (2000). *The feeling of what happens: Body and emotion in the making of consciousness.* Harvest.

- Damasio, A. (2005). *Descartes' error: Emotion, reason and the human brain.* Penguin Books (Originally published 1994).

- Darwin, C. (2009) *The Expression of Emotions in Man and Animals. Penguin.* [Kindle Version] (Originally published 1872)

- Delazio, A., Nakagaki, K., Klatzky, R.L, Hudson, S. E, Lehman, J. F,& Sample, A. P. (2018). Force Jacket: Pneumatically-Actuated Jacket for Embodied Haptic Experiences. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). Association for Computing Machinery, New York, NY, USA, Paper 320, 1–12. DOI:https://doi.org/10.1145/3173574.3173894

- Dennenberg, V. (1990). Mother-infant touch in animals. In N. Gunzenhauser, B. Brazelton, and T. Field. Advances in Touch, 3-10. Skillman, Johnson and Johnson.

- Desmet, P. M. A., & Hekkert, P. (2007). Framework of product experience. International Journal of Design, 1(1), 57-66.

- Desmet, P. M. A., & Hekkert, P. (2009). Special issue editorial: Design & emotion. IntemationalJoumal of Design, 3(2), 1-6.

- Di Mascio, A., Boyd, R. W., Greenblatt, M (1957). Physiological correlates of tension and antagonism during psychotherapy; a study of interpersonal physiology. Psychosomatic medicine, 19(2), 99–104. https://doi.org/10.1097/00006842-195703000-00002

- Di Mascio, A., Boyd, R. W., Greenblatt, M., & Solomon, H. C. (1955). The psychiatric interview: a sociophysiologic study. Diseases of the nervous system, 16(1), 4–9.

- Di Paolo, A. D., Rohde M., and De Jaegher H. (2010) Horizons of the mind: Values, social interaction, and play. In Steward J., Gapenne O., and Di Paolo E.A. (Eds.) Enaction: toward a new paradigm for cognitive science.

- Dixon, T. (2003). *From passions to emotions: The creation of a secular psychological category*. Cambridge University Press [Kindle Version].

- Dourish, P. (2004). *Where the action is: The foundations of embodied interaction*. MIT Press

- Dunn, B. D., Dalgleish, T., Ogilvie, A. D., & Lawrence, A. D. (2007). Heartbeat perception in depression. Behaviour Research and Therapy, 45(8), 1921–1930. https://doi.org/10.1016/j.brat.2006.09.008

- Dunn, B. D., Stefanovitch, I., Evans, D., Oliver, C., Hawkins, A., & Dalgleish, T. (2010). Can you feel the beat? Interoceptive awareness is an interactive function of anxiety- and depression-specific symptom dimensions. Behaviour Research and Therapy 48(11), 1133-1138. https://

doi:10.1016/j.brat.2010.07.006

- Dunn, B. D., Stefanovitch, I., Evans, D., Oliver, C., Hawkins, A., Dalgleish, T. (2010) Can you feel the beat? Interoceptive awareness is an interactive function of anxiety- and depression-specific symptom dimensions. Behaviour Research and Therapy 48, 11: 1133-1138.

- Ekman, P. (1984). Expression and the nature of emotion, in Approaches to Emotion, eds K. Scherer and P. Ekman. Erlbaum.

- Ekman, P. (1992). An argument for basic emotions. Cogn. Emot. 6, 169–200. doi: 10.1080/02699939208411068

- Enriquez, M.J, MacLean, K.E. (2003) The Hapticon Editor: A Tool in Support of Haptic Communication Research, Proc. 11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, IEEE

- Eron, K., Kohnert, L., Watters, A., Logan, C., Weisner-Rose, M., & Mehler, P. S. (2020). Weighted Blanket Use: A Systematic Review. The American journal of occupational therapy : official publication of the American Occupational Therapy Association, 74(2), 7402205010p1–7402205010p14. https://doi.org/10.5014/ajot.2020.037358

- Esrock E. J. (2018). Einfühlung as the breath of art: six modes of embodiment. Cognitive processing, 19(2), 187–199. https://doi.org/10.1007/s10339-017-0835-4

- Etzi, R., & Gallace, A. (2016). The arousing power of everyday materials: An analysis of the physiological and behavioral responses to visually and tactually presented textures. Experimental Brain Research, 234(6), 1659-1666. doi:10.1007/s00221-016-4574-z

- Feh, Claudia & De Mazières, Jeanne., (1993) Grooming at a preferred site reduces heart rate in horses. Animal Behaviour 46 (6), 1191–1194.

- Feldman R, Magori-Cohen R, Galili G, Singer M, & Louzoun, Y. Mother and infant coordinate heart rhythms through episodes of interaction synchrony. Infant Behavior and Development. 2011 Dec;34(4):569-77. doi: 10.1016/j.infbeh.2011.06.008. Epub 2011 Jul 20. PMID: 21767879

- Ferrari P.F. & Rizzolatti G. (2014). Mirror neuron research: the past and the future. Philosophical Transactions of the Royal Society B. 369: 20130169. http://dx.doi.org/10.1098/rstb.2013.0169

- Ferrell-Torry, A. T., & Glick, O. J. (1993). The use of therapeutic massage as a nursing intervention to modify anxiety and the perception of cancer pain. Cancer nursing, 16(2), 93–101.

- Ferrer, E., & Helm, J. L. (2013). Dynamical systems modeling of physiological coregulation in dyadic interactions. International Journal of Psychophysiology 88, 296-308.

- Ferron, J. (1976). Comfort behaviour of the red squirrel (tamiascilarus hudsonicus). Zeitshrift für Tierpsychologie, 42 (1), 66–85.

- Field, T. (2014). *Touch.* MIT Press

- Field, T., Hernandez-Reif, M., Diego, M., Schanberg, S., & Kuhn, C. (2005). Cortisol decreases and serotonin and dopamine increase following massage therapy. The International Journal of Neuroscience, 115(10), 1397–1413. https://doi.org/10.1080/00207450590956459

- Fiske, A. P. (2004). Four Modes of Constituting Relationships: Consubstantial Assimilation; Space, Magnitude, Time, and Force; Concrete Procedures; Abstract Symbolism. In N. Haslam (Ed.), Relational models theory: A contemporary overview (pp. 61–146). Lawrence Erlbaum Associates Publishers.

- Friedman B. H. (2010). Feelings and the body: the Jamesian perspective on autonomic specificity of emotion. Biological psychology, 84(3), 383–393. https://doi.org/10.1016/j.biopsycho.2009.10.006

- Fulkerson, M., 2011, The unity of haptic touch. Philosophical Psychology, 24(4): 493–516.

- Furlan, A. D., Giraldo, M., Baskwill, A., Irvin, E., & Imamura, M. (2015). Massage for low-back pain. The Cochrane Database of Systematic Reviews, (9), CD001929. https://doi.org/10.1002/14651858.CD001929.pub3

- Gallace, A. C. Spence. (2014). *In touch with the future: The sense of touch from cognitive neuroscience to virtual reality.* Oxford University Press.

- Gallese V. (2001) The “shared manifold” hypothesis: from mirror neurons to empathy. Journal of Consciousness Studies, 8:33–50.

- Gallese, V. (2009) Mirror neurons, embodied simulation, and the neural basis of social identification. Psychoanalytic Dialogues 19(5):519–536.

https://doi.org/10.1080/10481880903231910

- Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. Trends in cognitive sciences, 8(9), 396–403. https://doi.org/10.1016/j.tics.2004.07.002

- Galloway et al., (2017) Fabric-based soft actuators. US patent. 20190015233

- Ganczarek, J., Hünefeldt, T. & Olivetti Belardinelli, M. From "Einfühlung" to empathy: exploring the relationship between aesthetic and interpersonal experience. Cogn Process 19, 141–145 (2018). https://doi.org/10.1007/s10339-018-0861-x

- Garfinkel SN, Seth AK, Barrett AB, Suzuki K, Critchley HD. (2015) Knowing your own heart: distinguishing interoceptive accuracy from interoceptive awareness. Biological Psychology 104, 65–74. https://doi:10.1016/j.biopsycho.2014.11.004

- Garner, B., Phillips, L. J., Schmidt, H. M., Markulev, C., O'Connor, J., Wood, S. J., Berger, G. E., Burnett, P., & McGorry, P. D. (2008). Pilot study evaluating the effect of massage therapy on stress, anxiety and aggression in a young adult psychiatric inpatient unit. The Australian and New Zealand journal of psychiatry, 42(5), 414–422. https://doi.org/10.1080/00048670801961131

- Geldard, F. A. (1960). Some neglected possibilities of communication. Science, 131, 1583–1588. https://doi.org/10.1126/science.131.3413.1583

- Gendron, M., & Barrett, L. F. (2009). Reconstructing the Past: A Century of Ideas About Emotion in Psychology. Emotion review : journal of the International Society for Research on Emotion, 1(4), 316–339. https://doi.org/10.1177/1754073909338877

- Gershon, M. (1999). *The second brain: A groundbreaking new understanding of nervous disorders of the stomach and intestine*. Harper.

- Ghandeharioun, A., Picard, R.: BrightBeat: effortlessly influencing breathing for cultivating calmness and focus. In: Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA 2017), pp. 1624–1631 (2017). https://doi.org/10.1145/3027063.3053164

- Gianfaldoni, S., Tchernev, G., Wollina, U., Roccia, M. G., Fioranelli, M., Gianfaldoni, R., & Lotti, T. (2017). History of the Baths and Thermal

Medicine. Open Access Macedonian Journal of Medical Sciences, 5(4), 566–568. https://doi.org/10.3889/oamjms.2017.126

- Glass, L. (1996). Synchronization and rhythmic processes in physiology. Nature, 410 (6825), 277- 284 https://www.psychologytoday.com/us/blog/inner-source/201407/cold-splash-hydrotherapy-depression-and-anxiety

- Gozde Goncu-Berk, Ruoyu Zhang, and Cigdem Yilmaz. 2021. CalmWear: A Smart Tactile Sensory Stimulation Clothing. 2021 International Symposium on Wearable Computers. Association for Computing Machinery, New York, NY, USA, 184–188. DOI:https://doi.org/10.1145/3460421.3478829

- Grandin T. (1992). Calming effects of deep touch pressure in patients with autistic disorder, college students, and animals. Journal of child and adolescent psychopharmacology, 2(1), 63–72. https://doi.org/10.1089/cap.1992.2.63 (retrieved from https://www.grandin.com/inc/squeeze.html)

- Grandin T., Scariano M. (1986) *Emergence: Labeled Autistic.* Arena Press

- Griffin, C. E., 3rd, Kaye, A. M., Bueno, F. R., & Kaye, A. D. (2013). Benzodiazepine pharmacology and central nervous system-mediated effects. The Ochsner Journal, 13(2), 214–223.

- Grippa G., Rognoli, V. & Levi, M. (2012) Materials and emotions: A study on the relations between materials and emotions in industrial products. Proceedings of 8th International Design and Emotion Conference. London 2012 Central Saint Martins College of Art & Design, 11-14 September 2012

- Grynberg, D., & Pollatos, O. (2015). Perceiving one's body shapes empathy. Physiology & behavior, 140, 54–60. https://doi.org/10.1016/j.physbeh.2014.12.026

- Grynberg, D., & Pollatos, O. (2015). Perceiving one's body shapes empathy. Physiology & Behavior, 40-60. https://doi.org/10.1016/j.physbeh.2014.12.026

- Guinchat V, Vlamynck E, Diaz L, Chambon C, Pouzenc J, Cravero C, Baeza-Velasco C, Hamonet C, Xavier J, Cohen D. (2020) Compressive Garments in Individuals with Autism and Severe Proprioceptive Dysfunction: A Retrospective Exploratory Case Series. Children. 7(7):77. https://doi.org/10.3390/children7070077

- Haans, A., IJsselsteijn, W. (2006) Mediated social touch: a review of current research and future directions. Virtual Reality 9, 149–159. https://doi.org/10.1007/s10055-005-0014-2

- Halacy, D. S. (1965). *Cyborg, Evolution of the Superman*. Harper & Row.

- Harlow, H. F. & Zimmermann, R. R. (1958). The development of affective responsiveness in infant monkeys. Proceedings of the American Philosophical Society, 102,501-509.

- Harlow, H. F. (1958). The nature of love. American Psychologist, 13(12), 673–685. https://doi.org/10.1037/h0047884

- Hatfield, E., Cacioppo J., & Rapson R. L. (1994) *Emotional Contagion.* Cambridge University Press

- Hedlund, L., & Gyllensten, A. L. (2010). The experiences of basic body awareness therapy in patients with schizophrenia. Journal of Bodywork and Movement Therapies, 14(3), 245–254. https://doi.org/10.1016/j.jbmt.2009.03.002

- Helm, J. L., Sbarra, D. A., & Ferrer, E. (2014). Coregulation of respiratory sinus arrhythmia in adult romantic partners. Emotion (Washington, D.C.), 14(3), 522–531. https://doi.org/10.1037/a0035960

- Hertenstein, M.J., Holmes, R., McCullough, M., and Keltner, D. 2009. The communication of emotion via touch. Emotion 9: 566–73. doi:10.1037/a0016108

- Hertenstein, M.J., Keltner, D., App, B., Bulleit, B.A., and Jaskolka, A.R. 2006. Touch communicates distinct emotions. Emotion 6: 528–33. doi:10.1037/1528-3542.6. 3.528

- Hofer M.A. (1978). Hidden Regulatory Processes in Early Social Relationships. In: Bateson P.P.G. &, Klopfer, P.H. (Eds) Social Behavior. Perspectives in Ethology, vol 3. Springer. https://doi.org/10.1007/978-1-4684-2901-5_7

- Holt-Lunstad, J., Birmingham, W. A., & Light, K. C. (2008). Influence of a “warm touch” support enhancement intervention among married couples on ambulatory blood pressure, oxytocin, alpha amylase, and cortisol. Psychosomatic Medicine, 70(9), 976–985. https://doi.org/10.1097/PSY.0b013e318187aef7

- Hou, W. H., Chiang, P. T., Hsu, T. Y., Chiu, S. Y., & Yen, Y. C. (2010).

Treatment effects of massage therapy in depressed people: a meta-analysis. The Journal of Clinical Psychiatry, 71(7), 894–901. https://doi.org/10.4088/JCP.09r05009blu

- Howes, D. (Ed.). (2005). *Empire of the senses: The sensual culture reader.* Berg.

- Huisman, G., Darriba Frederiks, A., Van Dijk, B., Hevlen D., and Kröse, B. (2013) The TaSSt: Tactile sleeve for social touch. 2013 World Haptics Conference (WHC), 2013, pp. 211-216, doi: 10.1109/WHC.2013.6548410.

- Huynh, T.T.T.; Aarnink, A.J.A.; Gerrits, W.J.J.; Heetkamp, M.J.H.; Canh, T.T.; Spoolder, H.A.M.; Kemp, B.; & Verstegen, M.W.A. (2005). Thermal behaviour of growing pigs in response to high temperature and humidity. Applied Animal Behaviour Science. 91 (1–2): 1–16.

- IJzerman, H., and Semin, G.R. 2009. The thermometer of social relations: map- ping social proximity on temperature. Psychol. Sci. 20: 1214–20. doi:10.1111/j. 1467- 9280.2009.02434.x

- Ingold, T. (2013). *Making.* Routledge.

- Ishii, H., Lakatos, D., Bonanni, L., Labrune, J.B.: Radical atoms: beyond tangible bits, toward transformable materials. Interact. 19(1), 38–51 (2012). https://doi.org/10.1145/ 2065327.2065337

- Iyengar, B.K.S (1977). *Light on Yoga.* Schonken. (Originally published 1966)

- Iyengar, B.K.S (1993). *Light on the Yoga Sutras of Patanjali.* Thorsons. (Originally published 1966)

- Iyengar, B.K.S (2013) *Light on pranayama: The definitive guide to the art of breathing.* HarperCollins (Originally pubished 1981)

- James, W. (2007) *What is an Emotion?* Wilder [Kindle Version] (Originally published 1884)

- Jerath, R., Crawford, M. W., Barnes, V. A., & Harden, K. (2015). Self-regulation of breathing as a primary treatment for anxiety. Applied psychophysiology and biofeedback, 40(2), 107–115. https://doi.org/10.1007/s10484-015-9279-8

- Jerath, R., Edry, J. W., Barnes, V. A., & Jerath, V. (2006). Physiology of long pranayamic breathing: neural respiratory elements may provide a mechanism that explains how slow deep breathing shifts the autonomic nervous system. Medical Hypotheses, 67(3), 566–571. https://doi.org/10.1016/j.mehy.2006.02.042

- Johnson D, Tierney M, Sadighi P. Kapalabhati pranayama: breath of fire or cause of pneumothorax? A case report. CHEST 2004;125(5):1951–2.

- Johnson, M. (1990) *The body in the mind: The bodily basis of meaning, imagination, and reason.* University of Chicago Press

- Jones, M.R. (1976). Time, Our Lost Dimension: Toward a New Theory of Perception, Attention, and Memory. Psychological Review, 83(5), 323-355.

- Jones, M.R. and Boltz, M. (1989). Dynamic attending and responses to time. Psychological Review, 96(3), 459-491.

- Kanbara, K., & Fukunaga, M. (2016). Links among emotional awareness, somatic awareness and autonomic homeostatic processing. BioPsychoSocial Medicine, 10, Article 16. https://doi.org/10.1186/s13030-016-0059-3

- Karana, E., Pedgley, O., & Rognoli, V. (2014). *Materials experience: fundamentals of materials and design.* Oxford: Butterworth-Heinemann.

- Kashdan, T. B., Barrett, L. F., & Mcknight, P. E. (2015). Unpacking emotion differentiation. Current Directions in Psychological Science, 24(1), 10-16. https://doi.org/10.1177/0963721414550708

- Keles, H. Y., Özkar, M., & Tari, S. (2012). Weighted Shapes for Embedding Perceived Wholes. Environment and Planning B: Planning and Design, 39(2), 360–375. https://doi.org/10.1068/b37067

- Kim, K.H., Lee, M.S, Kim, T.H., Kang, J.W., Choi, T.Y., & Lee, J.D. Acupuncture and related interventions for symptoms of chronic kidney disease. Cochrane Database Syst Rev. 2016 Jun 28;(6):CD009440. https://doi.org/10.1002/14651858.CD009440.pub2. PMID: 27349639

- Kline, R. R. (2015). *The cybernetics moment, or, why we call our age the information age.* Johns Hopkins University Press.

- Knight T. and Stiny G. (2015) “Making grammars: from computing with shapes to computing with things” Design Studies Vol 41 Part A, pp. 8-28.

- Knight, T. (2003a). Computing with Emergence. Environment and Planning B: Planning and Design, 30(1), 125-155. doi:10.1068/b12914

- Knight, T. (2003b). Computing with Ambiguity. Environment and Planning B: Planning and Design, 30(2), 165-180. doi:10.1068/b12915

- Knight, T. & Stiny, G. (2015) Making grammars: from computing with shapes to computing with things. Design Studies 41 Part A, 8-28.

- Knight, T. Shapes and other things. Nexus Network Journal 17, 963–980 (2015). https://doi.org/10.1007/s00004-015-0267-3

- Knight, T. W. (1994). Shape Grammars and Color Grammars in Design. Environment and Planning B: Planning and Design, 21(6), 705–735. https://doi.org/10.1068/b210705

- Knuuttila, S. (2018) Medieval Theories of the Emotions. The Stanford Encyclopedia of Philosophy. Summer 2018 Edition. Edward N. Zalta (ed.). URL = <https://plato.stanford.edu/archives/sum2018/entries/medieval-emotions/>.

- Kober, A, Scheck, T, Schubert, B, Strasser, H, Gustorff, B, Bertalanffy, P, Wang, S.M, Kain, Z.N. & Hoerauf, K. Auricular acupressure as a treatment for anxiety in prehospital transport settings. Anesthesiology. 2003 Jun;98(6):1328-32. https://doi.org/10.1097/00000542-200306000-00005. PMID: 12766639

- Konstan, D. (2006). The concept of “emotion” from Plato to Cicero. Méthexis, 19, 139–151. https://doi.org/10.1163/24680974-90000497

- L. B., Bingham, J., Klundt, J., Bailey, R. J., Ripplinger, C., Kirchhoefer, J., Gibson, R., Griner, D., Cox, J. C., & Boardman, R. D. (2016). Sunshine on my shoulders: Weather, pollution, and emotional distress. Journal of Affective Disorders, 205, 234–238. https://doi.org/10.1016/j.jad.2016.07.021

- La France, M. (1982). Posture Mirroring and Rapport. In M. Davis (Ed.) Interaction rhythms: Periodicity in communicative behavior. (pp. 279–299). New York: Human Sciences Press.

- Lameira, A.R., Eerola, T. & Ravignani, A. Coupled whole-body rhythmic entrainment between two chimpanzees. Sci Rep 9, 18914 (2019). https://doi.org/10.1038/s41598-019-55360-y

- Lameira, A.R., Eerola, T. & Ravignani, A. Coupled whole-body rhythmic entrainment between two chimpanzees. Scientific Reports 9, 18914 (2019). https://doi.org/10.1038/s41598-019-55360-y

- Lamm, C., & Majdandžić, J. (2015). The role of shared neural activations, mirror neurons, and morality in empathy--a critical comment. Neuroscience research, 90, 15–24. https://doi.org/10.1016/j.neures.2014.10.008

- Lamm, C., & Majdandžić, J. (2015). The role of shared neural activations, mirror neurons, and morality in empathy--a critical comment. Neuroscience research, 90, 15–24. https://doi.org/10.1016/j.neures.2014.10.008

- Lane, R. D. (2006). Theory of emotional awareness and brain processing of emotion. International Congress Series, 1287, 116-121. https://doi.org/10.1016/j.ics.2005.12.041

- Lane, R. D. (2008). Neural Substrates of Implicit and Explicit Emotional Processes: A Unifying Framework for Psychosomatic Medicine. Psychosomatic Medicine, 70(2), 214-231. https://doi.org/10.1097/psy.0b013e3181647e44

- Lanzoni, S. (2018)*. Empathy: A History.* Yale University Press.

- Lazarus, RS & Folkman, S. (1984) *Stress, appraisal, and coping.* Springer

- Lee, E., J., Sherry Warden, The effects of acupuncture on serotonin metabolism, European Journal of Integrative Medicine, Volume 8, Issue 4, 2016, (355-367), ISSN 1876-3820,https://doi.org/10.1016/j.eujim.2016.06.022.

- Lee, V. (1913) The Beautiful: An Introduction to Psychological Aesthetics. University Press. Putnam’s Sons [Kindle Version]

- Levenson, R. W., & Gottman, J. M. (1983). Marital interaction: Physiological linkage and affective exchange. Journal of Personality and Social Psychology, 45(3), 587–597. https://doi.org/10.1037/0022-3514.45.3.587

- Levenson, R. W., & Gottman, J. M. (1983). Marital interaction: Physiological linkage and affective exchange. Journal of Personality and Social Psychology, 45(3), 587–597. https://doi.org/10.1037/0022-3514.45.3.587

- Levine, S. (1962). Plasma-free corticosteroid response to electric shock in rats stimulated in infancy. Science 135, 795-796

- Lewes G H, (1875) Problems of Life and Mind. Osgood and Company.

- Lipps T (1903) Ästhetik. Psychologie des Schönen und der Kunst (vol. 1: Grundlegung der Ästhetik). Leopold Voss, Leipzig

- Lipps T (1906) Ästhetik. Psychologie des Schönen und der Kunst (vol. 2: Die ästhetische Betrachtung und die bildende Kunst). Leopold Voss, Leipzig

- Liu, S., Zhou, Y., Palumbo, R., & Wang, J. L. (2016). Dynamical correlation: A new method for quantifying synchrony with multivariate intensive longitudinal data. Psychological Methods, 21(3), 291–308. https://doi.org/10.1037/met0000071

- Liu, Y., Nishikawa, S., Seong, Y., Niiyama, R., Kuniyoshi, Y., (2021). ThermoCaress: A Wearable Haptic Device with Illusory Moving Thermal Stimulation. Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, Article 214, 1–12. DOI:https://doi.org/10.1145/3411764.3445777

- Lomax, A. (1982). The cross-cultural variation of rhythmic style. In M. Davis (Ed.), Interaction rhythms. Periodicity in human behavior. New York: Human Sciences Press.

- Lomax, A. (1982). The cross-cultural variation of rhythmic style. In Davis, M. (Ed.), Interaction rhythms. Periodicity in human behavior. Human Sciences Press.

- Loomis, J. and S. Lederman. (1986) Tactual perception. In Boff, K.R., Kaufman L. & Thomas, J.P. (eds), Handbook of Perception and Human Performance, Ch. 31, Wiley and Sons.

- Lumpkin, E.A. and Caterina, M.J. (2007)“Mechanisms of sensory transduction in the skin. Nature, 445(7130): 858–865.

- MacLean P.D. (1988) Triune Brain. In: Comparative Neuroscience and Neurobiology. Readings from the Encyclopedia of Neuroscience. Birkhäuser, Boston, MA. https://doi.org/10.1007/978-1-4899-6776-3_51

- Malafouris, L. (2004). The cognitive basis of material engagement: where brain, body and culture conflate. In E. DeMarrais, C. Gosden, & C. Renfrew (Eds.), Rethinking materiality: The engagement of mind with the material world (pp. 53e62). Cambridge: McDonald Institute Monographs.

- McGrath, J. E. and Kelly, J.R. (1986). *Time and Human Interaction: Toward a Social Psychology of Time.* Guilford Press.

- McMunn, R. (2014) *Spatial Reasoning Tests. The testing series.* How2become.

- McNeil, W. H (1995). *Keeping together in time: Dance and drill in human history.* Harvard University Press

- Mead M. N. (2008). Benefits of sunlight: a bright spot for human health. Environmental Health Perspectives, 116(4), A160–A167. https://doi.org/10.1289/ehp.116-a160

- Mill J S, (1843) *System of Logic.* Longmans, Green, Reader, and Dyer.

- Moberg KU, Handlin L, Petersson M. Neuroendocrine mechanisms involved in the physiological effects caused by skin-to-skin contact - With a particular focus on the oxytocinergic system. Infant Behavior and Development 2020 Nov;61:101482. https://doi.org/10.1016/j.infbeh.2020.101482. Epub 2020 Sep 10. PMID: 32919112.

- Mooney R. (2014). Auditory–vocal mirroring in songbirds. Philosophical Transactions of the Royal Society B 369, 20130179. https://doi.org/10.1098/rstb.2013.0179

- Moran, G., Fentress, J.C., and Golani, I. (1981). A description of relational patterns during “ritualized fighting” in wolves. Animal Behavior: 29: 1146-1165

- Morelli, S. A., Rameson, L. T., & Lieberman, M. D. (2014). The neural components of empathy: predicting daily prosocial behavior. Social cognitive and affective neuroscience, 9(1), 39–47. https://doi.org/10.1093/scan/nss088

- Morelli, S.A., Rameson, L.T., Lieberman, M.D., 2014. The neural components of empathy: predicting daily prosocial behavior. Social Cognitive and Affective Neuroscience 9, 39–47.

- Mu, Y., Han, S., & Gelfand, M. J. (2017). The role of gamma interbrain synchrony in social coordination when humans face territorial threats. Social cognitive and affective neuroscience, 12(10), 1614–1623. https://doi.org/10.1093/scan/nsx093

- Mueller, F., Vetere, F., Gibbs, M. R. , Kjeldskov, J., Pedell, S., & Howard, S. (2005). Hug over a distance. In CHI ‘05 Extended Abstracts on Human Factors in Computing Systems (CHI EA ‘05). Association for Computing Machinery, New York, NY, USA, 1673–1676. DOI:https://doi.org/10.1145/1056808.1056994

- Noë, A. (2006) *Action in perception.* MIT Press

- Norman, Greg & Norris, Catherine & Gollan, Jackie & Ito, Tiffany & Hawkley, Louise & Larsen, Jeff & Cacioppo, John & Berntson, Gary. (2011). Current Emotion Research in Psychophysiology: The Neurobiology of Evaluative Bivalence. Emotion Review. 3. 349-359. 10.1177/1754073911402403.

- Ou J., Skouras, M., Vlavianos, N., … and Hiroshi Ishii, H.. 2016. AeroMorph - Heat-sealing Inflatable Shape-change Materials for Interaction Design. (2016) In Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST ‘16). Association for Computing Machinery, New York, NY, USA, 121–132. DOI:https://doi.org/10.1145/2984511.2984520

- Ozgun Kilic Afsar, Ali Shtarbanov, Hila Mor, Ken Nakagaki, Jack Forman, Karen Modrei, Seung Hee Jeong, Klas Hjort, Kristina Höök, Hiroshi Ishii. OmniFiber: Integrated Fluidic Fiber Actuators for Weaving Movement based Interactions into the ‘Fabric of Everyday Life’. UIST ‘21: The 34th Annual ACM Symposium on User Interface Software and Technology, October 2021 Pages 1010%u20131026 DOI: 10.1145/3472749.3474802

- Pal G, Velkumary S, Madanmohan. Effect of short-term practice of breathing exercises on autonomic functions in normal human volunteers. Indian Journal of Medical Research 2004;120(2): 115–21.

- Pallasmaa, J. (1996). *The eyes of the skin.* Wiley.

- Pallasmaa, J. (2011). *The embodied image: Imagination and imagery in architecture.* John Wiley & Sons Inc.

- Palumbo, R. V., Marraccini, M. E., Weyandt, L. L., Wilder-Smith, O., McGee, H. A., Liu, S., & Goodwin, M. S. (2017). Interpersonal autonomic physiology: a systematic review of the literature. Personality and Social Psychology review : an official journal of the Society for Personality and Social Psychology, Inc, 21(2), 99–141. https://doi.org/10.1177/1088868316628405

- Palumbo, R. V., Marraccini, M. E., Weyandt, L. L., Wilder-Smith, O., McGee, H. A., Liu, S., & Goodwin, M. S. (2017). Interpersonal

Autonomic Physiology: A Systematic Review of the Literature. Personality and social psychology review : an official journal of the Society for Personality and Social Psychology, Inc, 21(2), 99–141. https://doi.org/10.1177/1088868316628405

- Papadopoulou, A., Berry, J., Knight, T., and Picard, R. (2019). Affective Sleeve: Wearable Materials with Haptic Action for Promoting Calmness. Proceedings of 21st International Conference on Human Computer Interaction (HCII). Orlando, Florida, USA, 26-31 July 2019

- Parkinson, C., Kleinbaum, A.M. & Wheatley, T. Similar neural responses predict friendship. Nat Commun 9, 332 (2018). https://doi.org/10.1038/s41467-017-02722-7

- Perry, D., Hendler, T., & Shamay-Tsoory, S. G. (2012). Can we share the joy of others? Empathic neural responses to distress vs joy. Social cognitive and affective neuroscience, 7(8), 909–916. https://doi.org/10.1093/scan/nsr073

- Phillips-Silver, J., Aktipis, C. A., & Bryant, G. A. (2010). The ecology of entrainment: Foundations of coordinated rhythmic movement. Music perception, 28(1), 3–14. https://doi.org/10.1525/mp.2010.28.1.3

- Picard, R. W., Fedor, S., & Ayzenberg, Y. (2016). Multiple Arousal Theory and Daily-Life Electrodermal Activity Asymmetry. Emotion Review, 8(1), 62–75. https://doi.org/10.1177/1754073914565517

- Picard, R., (2000). Affective Computing. Cambridge, MA: MIT Press. (Originally published in 1997)

- Pirnia, B., Mohammadzadeh Bazargan, N., Hamdieh, M., Pirnia, K., Malekanmehr, P., Maleki, F., & Zahiroddin, A. (2019). The effectiveness of auricular acupuncture on the levels of cortisol in a depressed patient. Iranian Journal of Public Health, 48(9), 1748–1750.

- Pisani, S., Murphy, J., Conway, J., Millgate, E., Catmur, C., & Bird, G. (2021). The relationship between alexithymia and theory of mind: A systematic review. Neuroscience and biobehavioral reviews, 131, 497–524. Advance online publication. https://doi.org/10.1016/j.neubiorev.2021.09.036

- Plans, D., Ponzo, S., Morelli, D., Cairo, M., Ring, C., Keating, C.T., Cunningham, A.C., Catmur, C., Murphy, J., & Bird, G. (2021). Measuring interoception: The phase adjustment task. Biological Psychology, 165.

- Plato (2003). *The Republic* (Desmond, L., Trans.). Penguin (Originally published ca. 375 B.C.E)

- Plutchik, Robert (1980), Emotion: Theory, research, and experience: Vol. 1, in *Theories of emotion, 1*. Academic

- Poffenberger, A. T., & Barrows, B. E. (1924). The Feeling Value of Lines. Journal of Applied Psychology, 8(2), 187–205. https://doi.org/10.1037/h0073513

- Pollatos, O., Herbert, B. M., Matthias, E., & Schandry, R. (2007). Heart rate response after emotional picture presentation is modulated by interoceptive awareness. International Journal of Psychophysiology, 63(1), 117-124. https://doi.org/10.1016/j.ijpsycho.2006.09.003

- Pollatos, O., Traut-Mattausch, E., & Schandry, R. (2009). Differential effects of anxiety and depression on interoceptive accuracy. Depression and Anxiety, 26(2), 167-173. https://doi.org/10.1002/da.20504

- Pollatos, O., Traut-Mattausch, E., Schroeder, H., Schandry, R.(2007). Interoceptive awareness mediates the relationship between anxiety and the intensity of unpleasant feelings. Journal of Anxiety Disorders 21, 7: 931-943. https://doi.org/10.1016/j.janxdis.2006.12.004.

- Prather JF, Peters S, Nowicki S, Mooney R. 2008 Precise auditory-vocal mirroring in neurons for learned vocal communication. Nature 451, 305 – 310. https//doi.org/10.1038/nature06492

- Ramasamy, R., Juhari, M. R., Sugisaka, M., & Osman, N. A. (2007). Pneumatic Artificial Muscle in Biomedical Applications. 3rd Kuala Lumpur International Conference on Biomedical Engineering 2006 IFMBE Proceedings, 219-221. doi:10.1007/978-3-540-68017-8_57

- Reed, C. M., Tan, H. Z., Perez, Z. D., Wilson, E. C., Severgnini, F. M., Jung, J., Martinez, J. S., Jiao, Y., Israr, A., Lau, F., Klumb, K., Turcott, R., & Abnousi, F. (2019). A Phonemic-Based Tactile Display for Speech Communication. IEEE transactions on haptics, 12(1), 2–17. https://doi.org/10.1109/TOH.2018.2861010

- Reed, R. G., Randall, A. K., Post, J. H., & Butler, E. A. (2013). Partner influence and in-phase versus anti-phase physiological linkage in romantic couples. International Journal of Psychophysiology, 88, 309-316.

- Rennung, M., & Göritz, A. S. (2016). Prosocial consequences of interpersonal synchrony. Zeitschrift Für Psychologie, 224(3), 168-189. doi:10.1027/2151-2604/a000252

- Rennung, M., & Göritz, A. S. (2016). Prosocial consequences of interpersonal synchrony: A meta-analysis. Zeitschrift für Psychologie, 224(3), 168-189. http://dx.doi.org/10.1027/2151-2604/a000252

- Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. Annual Review of Neuroscience, 27, 169–192. https://doi.org/10.1146/annurev.neuro.27.070203.144230

- Roquet, C. D., Sas, C.(2018). Evaluating Mindfulness Meditation Apps. In: Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI EA '18). ACM, New York, NY, USA, Paper LBW575, 6 pages. DOI: https://doi.org/10.1145/3170427.3188616 (2018).

- Rovers, A.F and Van Essen, H.A. (2004). HIM: a framework for haptic instant messaging. In CHI '04 Extended Abstracts on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, 1313–1316. DOI:https://doi.org/10.1145/985921.986052

- Ruggieri, V (2001) L'identità in psicologia e teatro. Analisi psicofisiologica della struttura. Ma.Gi, Rome.

- Ruggieri, V. (1997) Esperienza Estetica: Fondamenti Psicofisiologici per un'educazione Estetica. Armando Editore, Rome.

- Ruggieri, V., Fiorenza, M., & Sabatini, N. (1986) Visual decodification through micro-imitation. Perceptual Motor Skills 62:475–481.

- Russell J. A. (2003). Core affect and the psychological construction of emotion. Psychological review, 110(1), 145–172. https://doi.org/10.1037/0033-295x.110.1.145

- Russell, J. A. (1980). A circumplex model of affect. Journal of Personality and Social Psychology, 39(6), 1161–1178. https://doi.org/10.1037/h0077714

- Russell, J. A., & Barrett, L. F. (1999). Core affect, prototypical emotional episodes, and other things called emotion: dissecting the elephant. Journal of personality and social psychology, 76(5), 805–819. https://doi.org/10.1037//0022-3514.76.5.805

- Russell, J. A., Weiss, A., & Mendelsohn, G. A. (1989). Affect Grid: A single-item scale of pleasure and arousal. Journal of Personality and Social Psychology, 57(3), 493–502. https://doi.org/10.1037/0022-3514.57.3.493

- Russell, J. A., Weiss, A., & Mendelsohn, G. A. (1989). Affect Grid: A single-item scale of pleasure and arousal. Journal of Personality and Social Psychology, 57(3), 493–502. https://doi.org/10.1037/0022-3514.57.3.493

- Salminen, K., Surakka, V., Lylykangas, J., Raisamo, R., Saarinen, R., Raisamo, R., et al. 2008. Emotional and behavioral responses to haptic stimulation. In Proceeding of the Twenty-Sixth Annual SIGCHI Conference on Human Factors in Computing Systems, 1555–1562. New York, NY: ACM Press.

- Schachter, S., & Singer, J. (1962). Cognitive, social, and physiological determinants of emotional state. Psychological Review, 69(5), 379–399. https://doi.org/10.1037/h0046234

- Scheflen, A. E. (1964). The significance of posture in communication systems. Psychiatry: Journal for the Study of Interpersonal Processes, 27(4), 316–331.

- Sedeno, L., Couto, B., Melloni, M., Canales-Johnson, A., Yoris, A., Baez, S., . . . Ibanez, A. (2014). How Do You Feel when You Cant Feel Your Body? Interoception, Functional Connectivity and Emotional Processing in Depersonalization-Derealization Disorder. PLoS ONE, 9(6). doi:10.1371/journal.pone.0098769

- Sedeño, L., Couto, B., Melloni, M., Canales-Johnson, A., Yoris, A., Baez, S., . . . Ibanez, A. (2014). How do you feel when you can't feel your body? Interoception, functional connectivity and emotional processing in depersonalization-derealization disorder. PLOS ONE, 9(6). https://doi.org/10.1371/journal.pone.0098769

- Sellars, J. (2014) *Stoicism (Ancient Philosophies)*. Routledge [Kindle Version].

- Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. Trends in Cognitive Sciences, 17(11), 565-573. https://doi.org/10.1016/j.tics.2013.09.007

- Shannon, C. E., & Weaver, W. (1998). T*he Mathematical Theory of Communication.* University of Illinois Press. (Originally published 1948)

- Shon, D. (1987). *Educating the Reflective Practitioner: Toward a new design for teaching and learning in the professions*. Jossey-Bass Publishers.

- Shu, J., Hassell, S., Weber, J., Ochsner, K. N., & Mobbs, D. (2017). The role of empathy in experiencing vicarious anxiety. Journal of Experimental Psychology. General, 146(8), 1164–1188. https://doi.org/10.1037/xge0000335

- Sigley I. (2020). It has touched us all: Commentary on the social implications of touch during the COVID-19 pandemic. Social Sciences & Humanities Open, 2(1), 100051. https://doi.org/10.1016/j.ssaho.2020.100051

- Sigley I., (2021, Jan 24). Lost touch: How year without touch affects our mental health. The Guardian. https://www.theguardian.com/lifeandstyle/2021/jan/24/lost-touch-how-a-year-without-hugs-affects-our-mental-health

- Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R. J., & Frith, C. D. (2004). Empathy for pain involves the affective but not sensory components of pain. Science 303(5661), 1157–1162. https://doi.org/10.1126/science.1093535

- Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R. J., & Frith, C. D. (2004). Empathy for pain involves the affective but not sensory components of pain. Science (New York, N.Y.), 303(5661), 1157–1162. https://doi.org/10.1126/science.1093535

- Smith C.A., Armour, M., Lee, M.S., Wang, L.Q, & Hay, P.J. Acupuncture for depression. Cochrane Database of Systematic Reviews. 2018 Mar 4;3(3):CD004046. https://doi.org /10.1002/14651858.CD004046.pub4. PMID: 29502347; PMCID: PMC6494180.

- Smith, J., & MacLean, K.E. (2007). Communicating emotion through a haptic link: Design space and methodology. Int. J. Hum. Comput. Stud., 65, 376-387.

- Sparrman, B. & du Pasquier, C., Darbari, S., Rustom, R., Laucks, J., Shea, K. & Tibbits, S. (2021) "Printed Silicone Pneumatic Actuators for Soft Robotics", Additive Manufacturing, Article 101860.

- Stephenson, J., & Carter, M. (2009). The use of weighted vests with children with autism spectrum disorders and other disabilities. Journal of autism and developmental disorders, 39(1), 105–114. https://doi.org/10.1007/s10803-008-0605-3

- Stiny (2018, forthcoming). Calculating: Beyond Fancy in Imagination's Magical Realm. Retrieved from: https://ocw.mit.edu/courses/architecture/4-540-introduction-to-shape-grammars-i-fall-2018/syllabus/

- Stiny, G. (2006). *Shape: Talking about seeing and doing.* Cambridge, MA: MIT Press.

- Stiny, G. (2015) The Critic as Artist: Oscar Wilde's Prolegomena to Shape Grammars. Nexus Netw J 17, 723–758. https://doi.org/10.1007/s00004-015-0274-4

- Stiny, G. and J. Gips. (1972). Shape Grammars and the Generative Specification of Painting and Sculpture. In: Information Processing 71, ed. C. V. Freiman, 1460–1465. Amsterdam: North-Holland. Republished 1972 in: The Best Computer Papers of 1971, ed. O. R. Petrocelli, 125–135. Philadelphia: Auerbach.

- Stiny, G. and J. Gips. 1972. Shape grammars and the generative specification of painting and cculpture. In Freiman, C.V.(ed) Information Processing 71, 1460–1465. North- Holland. Republished 1972, In Petrocelli, O. R. (Ed.),The Best Computer Papers of 1971, Auerbach.

- Stiny, G. (forthcoming) accessed April 2, 2021 at https://ocw.mit.edu/courses/architecture/4-540-introduction-to-shape-grammars-i-fall-2018/course-texts/

- Story, T. J., & Craske, M. G. (2008). Responses to false physiological feedback in individuals with panic attacks and elevated anxiety sensitivity. Behaviour Research and Therapy, 46(9), 1001-1008. https://doi.org/10.1016/j.brat.2008.06.001

- Streeter, C. C., Jensen, J. E., Perlmutter, R. M., Cabral, H. J., Tian, H., Terhune, D. B., . . .Renshaw, P. F. (2007). Yoga asana sessions increase brain GABA levels: a pilot study. Journal of Alternative and Complementary Medicine, 13(4), 419-426. doi:10.1089/acm.2007.6338

- Streeter, C. C., Jensen, J. E., Perlmutter, R. M., Cabral, H. J., Tian, H., Terhune, D. B., Ciraulo, D. A., & Renshaw, P. F. (2007). Yoga Asana sessions increase brain GABA levels: a pilot study. Journal of alternative and complementary medicine (New York, N.Y.), 13(4), 419–426. https://doi.org/10.1089/acm.2007.6338

- Suhonen, K., Väänänen-Vainio-Mattila, K., and Mäkelä, K. (2012). User experi- ences and expectations of vibrotactile, thermal and squeeze feedback in inter- personal communication. In Proceedings of the 26th Annual BCS Interaction Specialist Group Conference on People and Computers BCS-HCI '12, 205–214. New York, NY: ACM.

- Suk, H.-J., Jeong, S.-H., Hang, T.-H., and Kwon, D.-S. 2009. Tactile sensation as emotion elicitor. Kansei Eng. Int. 8(2): 147–52.

- Sumioka, H., Nakae, A., Kanai, R., Ishiguro, H. (2013). Huggable communication medium decreases cortisol levels. Scientific Reports 3, 1. doi:10.1038/srep03034

- Summers, J. K., & Vivian, D. N. (2018). Ecotherapy – a Forgotten Ecosystem service: A review. Frontiers in Psychology, 9. https://doi.org/10.3389/fpsyg.2018.01389

- Sun, L. J., Li, J. N., & Nie, Y. Z. (2020). Gut hormones in microbiota-gut-brain cross-talk. Chinese medical journal, 133(7), 826–833. https://doi.org/10.1097/CM9.0000000000000706

- Suomi, S.J. (1995). Touch and the immune system in rhesus monkeys. In Field, T, (ed.), Touch in Early Development. 89-103. Johnson and Johnson.

- Tibbits, S. (2017). *Active Matter.* The MIT Press.

- Tibbits, S. (2021). Things fall together: A guide to the new materials revolution. Princeton University Press.

- Timmons, A. C., Margolin, G., & Saxbe, D. E. (2015). Physiological linkage in couples and its implications for individual and interpersonal functioning: A literature review. Journal of Family Psychology : JFP : Journal of the Division of Family Psychology of the American Psychological Association (Division 43), 29(5), 720–731. https://doi.org/10.1037/fam0000115

- Tomkins, S. S. (1962). *Affect, Imagery, Consciousness: The Positive Affects, Vol. 1*. Springer.

- Tsalamlal, M.Y., Ouarti, N., Martin, J.C., and Ammi, M. (2014). Haptic communication of dimensions of emotions using air jet based tactile stimulation. J. Multimodal User Interfaces 9(1): 69–77. doi:10.1007/s12193-014 -0162-3

- Tsalamlal, M.Y., Ouarti, N., Martin, J.C., and Ammi, M. (2014). Haptic communication of dimensions of emotions using air jet based tactile stimulation. J. Multimodal User Interfaces 9(1): 69–77. doi:10.1007/s12193-014 -0162-3

- Turpin, G. and Grandfield, T., (2007) Electrodermal Activity. In Fink G., (ed) Encyclopedia of Stress (Second Edition). Academic Press, 899-902, ISBN 9780123739476, https://doi.org/10.1016/B978-012373947-6.00139-2.

- Uvnäs-Moberg K. Neuroendocrinology of the mother-child interaction. Trends in Endocrinology and Metabolism, 1996 May-Jun;7(4):126-31. doi: 10.1016/1043-2760(96)00036-7. PMID: 18406738

- Van Der Kolk, B. (2015). *The Body Keeps the Score: Brain, Mind, and Body in the Healing of Trauma.* Penguin.

- Van Erp, J. B. F., & Toet, A. (2015). Social Touch in Human-Computer Interaction. Frontiers in Digital Humanties.

- Varela, F. J., Thompson, E. T., Rosch, E. (1991). *The Embodied Mind: Cognitive Science and Human Experience*. MIT Press

- Vernon, L & Thomson, A. C. (2017). *Beauty and Ugliness.* Andesite Press. (Originally published in 1897)

- Vischer R (1873) Über das optische Formgefühl. Ein Beitrag zur Ästhetik. Leipzig: Herman Credner [English edition: On the optical sense of form: a contribution to aesthetics. In: Mallgrave, HF, Ikonomou E (eds) (1994). Empathy, form, and space: problems in

german aesthetics, 1873–1893 (pp 89–123). Getty Center for the History of Art and the Humanities]

- Wang, Y., and Brown, M. (1996). A flexible model for human circadian rhythms. Biometrics, 52, 588- 596.

- Weaver, I., Cervoni, N., Champagne, F. et al. Epigenetic programming by maternal behavior. Natural Neuroscience 7, 847–854 (2004). https://doi.org/10.1038/nn1276

- White, C. N. (2016). *Interoceptive Awareness and Empathy.* Doctoral dissertation, University of Saint Louis

- Wiberg, M. (2018). *The materiality of interaction: Notes on the materials of interaction design.* Cambridge, MA: The MIT Press.

- Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., & Rizzolatti, G. (2003). Both of us disgusted in My insula: the common neural basis of seeing and feeling disgust. Neuron, 40(3), 655–664. https://doi.org/10.1016/s0896-6273(03)00679-2

- Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., & Rizzolatti, G. (2003). Both of us disgusted in My insula: the common neural basis of seeing and feeling disgust. Neuron, 40(3), 655–664. https://doi.

org/10.1016/s0896-6273(03)00679-2

- Wiener, N. (2019). *Cybernetics: Or, Control and communication in the animal and the machine.* The MIT Press.(Originally published in 1948)

- Wiesen, J. (2015) *Mechanical aptitude and spatial relations tests.* Barron's

- Wilde, O. (2014) *The Critic as Artist.* Oscar Wilde Collection Book 5. Ediciones74. [Kindle Version] (Originally published 1891)

- Wilhem W. (1986) *Outlines of Psychology.* Engelmann

- Wilkes, S. E., & Miodownik, M. A. (2018). Materials library collections as tools for interdisciplinary research. Interdisciplinary Science Reviews, 43(1), 3-23. doi:10.1080/03080188.2018.1435450

- Wolfflin H (1886) Prolegomena zu einer Psychologie der Architektur. Mann Verlag, Gebr

- Wu, D. J., Dong, H. C., Tang, T. N., & Zhu, S. F. (2018). Acupressure for insomnia: A protocol for systematic review and meta-analysis. Medicine, 97(45), e13180. https://doi.org/10.1097/MD.0000000000013180

- Wu, S. D., & Lo, P. C. (2010). Cardiorespiratory phase synchronization during normal rest and inward-attention meditation. International Journal of Cardiology, 141(3), 325-328. doi:10.1016/j.ijcard.2008.11.137

- Yano, J. M., et al., Yu, K., …, Mazmanian, S. K., Hsiao, E. Y., (2015). Indigenous bacteria from the gut microbiota regulate host serotonin biosynthesis. Cell 161, 264–276 http://dx.doi.org/10.1016/j.cell.2015.02.047

- Yao, L., Niiyama, R., JOu, J., Follmer, S., Silva, C., D., and Ishii, H., (2013). PneUI: pneumatically actuated soft composite materials for shape changing interfaces. In Proceedings of the 26th annual ACM symposium on User interface software and technology (UIST '13). ACM, New York, NY, USA, 13-22.

- Yasuma, F., & Hayano, J. Respiratory sinus arrhythmia: why does the heartbeat synchronize with respiratory rhythm? CHEST 2004 Feb;125(2):683-90. doi: 10.1378/chest.125.2.683. PMID: 14769752

- Zaccaro A, Piarulli A, Laurino M, Garbella E, Menicucci D, Neri B and Gemignani A (2018) How breath-control can change your life: a systematic review on psycho-physiological correlates of slow breathing. Frontiers in Human Neuroscience. 12:353. doi: 10.3389/fnhum.2018.0035

- Zahavi, D., (2014) *Self and Other: Exploring Subjectivity, Empathy, and Shame.* Oxford University Press.

- Zeng, H., Oian, Z., Myers, M., and Rosbash, M. (1996). A light-entrainment mechanism for the drosophila circadian clock. Nature, 380, 129-135.

- Zhang, Z. , Héron, R., Lecolinet, E. & Detienne, F., & Safin, S. (2019). VisualTouch: Enhancing Affective Touch Communication with Multi-modality Stimulation. 114-123. 10.1145/3340555.3353733.

- Zumthor, P. (2010) *Thinking Architecture.* Birkhäuser