Externalizing and Interpreting Autonomic Arousal in People Diagnosed with Autism

by

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Submitted to the Program of Media Arts and Sciences,
School of Architecture and Planning
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Abstract

This research explores how externalization of physiological states helps to provide an awareness of hidden stressors through a home-based study, a lab-based study, and a school-based study in order to facilitate social understanding of people who are non-speaking, especially those diagnosed with autism spectrum disorder (ASD). For people who experienced with hyper- or hypo-sensory responses (e.g., many people diagnosed with ASD), over-aroused situations or " meltdowns" are often accompanied by incorrect attributions of potential stressors in their everyday lives. A series of physiology-based technologies are implemented as a toolkit (e.g., providing in-situ visual and tactile feedback, or enabling interactive and analytical indexing of collected data) for assisting the interpretations of individuals' arousal states.

First, the home-based study is a participant-driven study following Kanner's perspective of documenting "fascinating peculiarities" in autism. I arrive in a family as an ethnographer documenting a dynamic process of hypothesizing and interpreting situations in order to seek a dialogue with a young man with ASD who is able to name objects, but does not use language in typical ways. Second, the lab-based study is a single-case design experiment with direct replications focusing on class teachers' interpretations of arousal states in students diagnosed with ASD. The goal of this study is to assess how real-time displays of student physiological activity (i.e. heart rate) affect teacher estimation of arousal and relaxation. The results suggest that arousal estimation varies as a function of how physiological information is displayed. Third, the school-based study presents a collaboration with an occupational therapist (OT) and three teenage participants with ASD. This study documents the iterated investigations of the OT's interpretations with and without the presence of students' physiological data (i.e. skin conductance data). This study demonstrates how participants' arousal information assists the OT in making judgments from a clinical perspective.

This dissertation presents an experimental method and toolkit to help calibrate typical assumptions about people diagnosed with ASD. With the intervention of physiology-based technologies, this research shows a novel approach of debugging reciprocal understanding of people in both naturalistic and experimental environments.

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For Edison

Chapter 1

Introduction

Detecting misunderstandings

> My one-year-old baby did not like his new shoes. He refused to wear them again. As his parents, we thought this could be his preference or his style. He might like other pairs of shoes more. A few weeks later, when my wife put the shoes into the wash, she found there was a wad of paper that usually came with new shoes stuck deep inside one of the shoes. Finally, we realized the hidden truth and why my son did not want to wear them.

Misunderstandings occur when interpretations are made with missing information. My one-year-old baby expressed emotions in the most primitive and non-verbal ways. He knew that it was not comfortable to wear the shoes so he did not want to wear them, but his parents were not aware of the reason. His expressions were honest, but the parents believed in their interpretations of things they saw. Before this baby started talking, there might be many other occasions when parents could misinterpret why the baby accepted or rejected. More examples might occur in family lives, offices, and hospitals. These unintended misunderstandings might create flaws in existing communication.

1.1 Introduction

Non-verbal individuals with autism spectrum disorder—ASD (APA, 1994; Baron et al., 2006; Happe, 1999; Kanner, 1943)—are often experienced with hyper- or hypo-sensitivity to stressors. In their daily lives, they are easily exposed to stressors without others' noticing. When their arousals exceed their capacity, tantrums,[1] meltdowns,[2] or other extreme emotional and over-aroused behaviors may occur. When an individual has a meltdown, people tend to focus on how to bring the individual back to normal, and they typically treat this event as an accident. The sequences of affective disturbances leading to the extreme emotional state are ignored. People tend to pay more attention to the extreme behavioral event instead of trying to understand the reasons that cause the individual stressed. However, extreme emotions and over-aroused behaviors occur with physiological characteristics. These physiological footprints may enable us to interpret the path of how a person got overwhelmed (e.g., a digging sound that may not be noticed by one person could really make another person uneasy, anxious, and aroused). This thesis explores how physiology-based technology might provide an awareness of hidden components that may have disturbed someone's emotions.

Using physiological sensors for characterizing human emotion is not a new idea. Let us consider a very different example: lie detection, an interrogation method to determine if a prisoner were telling a lie that was used during World War I (Lykken, 1991). Lie detection requires a dedicated observer—the interrogator— who is monitoring plots, observing the subject, using the subject's confession as ground truth, and checking the consistency of the subject's physiological and behavioral variance in order to tell if the subject is lying (Iacono, 2008). The interrogator uses a polygraph machine that measure physiological signals such as skin conductance, blood pressure, breathing rate, and heart rate (Verschuere, 2007).

This thesis focuses on the idea of externalization. Externalization refers forms of messages that directly relate to inner states. A smiling face typically means happy. However, it is difficult to infer someone's emotions from a plain face without any expression. Autonomic arousal states, as one type of inner states, can be measured objectively by physiological sensors. This thesis investigates how externalization helps communication, especially with people who have difficulties to communicate in typical ways. Goodwin et al. (2006) found inconsistency of arousal states and outward appearance in teenagers diagnosed with autism. By using technology to retrieve messages about arousal states, externalization could provides a channel to understand people whose over-aroused behaviors are typically misunderstood.[3]

Figure 1-1 presents a comparison between lie detection and externalization, as proposed in this dissertation. Lie detection and externalization share the underlying

[1] If a child has temper tantrums, s/he reacts emotionally in order to express his/her frustration.

[2] If a child experiences meltdowns, s/he loses the control of temper and does not consider his/her own safety.

[3] In Chapter 6, we found participant P06 (coded name) appeared calm, but her heart rate exceeded 120 beat-per-minute.

principles of recording physiology responses. In lie detection, the interrogator is completely in charge, is able to control the environment and equipment, and tries to interpret the subject's actions. Externalization provides a means for debugging misunderstandings between caregivers and non-verbal individuals with physiological information. Externalization is based on existing, typically long-term reciprocal relationships (e.g., teacher and student, parent and child, caregiver and care recipient). In lie detection, interrogators and subjects are randomly encountered and only interact for a short period of time. Externalization can be done in everyday life in order to discover how life situations become threats to one's internal states as an act of understanding. After lie detection, the interrogator obtains the results and leaves. After externalization, the caregiver may obtain shared understandings that help to move toward shared goals and to improve relationships. During the process, the caregiver is developing the knowledge of understanding this individual.

	Lie Detection	Externalization
Characterizing autonomic arousal	yes	yes
Reciprocal relationships	no	yes
Real-world Interaction	no	yes
Goal for improving relationship	no	yes

Figure 1-1. A comparison of *Lie Detection* and *Externalization*

Externalization aims to help communicate internal states and to assist therapeutic interpretations. Three studies are discussed below to investigate the processes of detecting misunderstandings: an in-depth case study, a lab-based experiment, and a school-based occupational therapy curriculum. This thesis demonstrates a mechanism that helps caregivers to explore false assumptions or incorrect attributions to situations that might cause extreme emotions. This should enrich understanding, especially of people who do not communicate the way the majority of people do.

1.2 Scope and Organization

This dissertation investigates the concept of externalizing and interpreting inner states by focusing on the interaction between people diagnosed with autism spectrum disorder (ASD) and their caregivers. Interpretation can be made based on existing hypotheses, assumptions, and available visual evidence. Externalization provides evidence and reference. Autonomic arousal is proposed as a means of externalization to provide information of inner states for interpretation. As shown in Figure 1-4, I decompose the process of understanding between a caregiver and an individual with ASD. A misunderstanding might occur when the caregiver's interpretation does not fully explain the situation due to a lack of information (e.g., the individual's externalization).

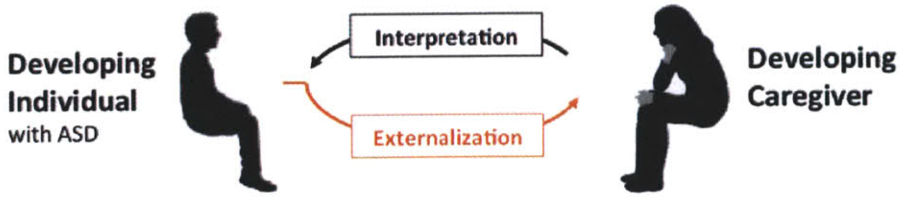

Figure 1-2. The process of understanding between a caregiver and an individual with ASD can be defined as a process of externalization and interpretation.

Table 1-1 shows the organization of this dissertation. I study detecting misunderstandings by focusing on the two elements, interpretation and externalization. In Chapter 2, I take three approaches to understanding autism from the literature: first, individual-driven study focuses on in-depth understanding of a person's behavior in his/her environment; second, the clinical-driven approach includes institutional perspectives of treating ill-behaviors of ASD individuals in therapeutic environments; third, the experimental-driven approach studies evidence-based research in seeking scientific explanations to problems found in the two previous approaches. I investigate these three approaches in a home-based, participant-driven study; a lab-based, experiment-driven study; and a school-based, therapy-driven study.

In Chapter 3, I investigate a series of theoretical models related to social understanding in order to characterize a systematic way of detecting misunderstandings with people diagnosed with autism. To investigate the quality of interpretation and externalization, this research attempts to characterize arousal-behavioral interpretations with scientific method and measurement in participants' real-world lives. The Externalization Toolkit, a set of physiology-based research prototypes covered in Chapter 4, is implemented for helping people with ASD to communicate their inner states based on the measurement of autonomic nervous system activities. Physiological displays developed in this research are built upon the iCalm skin conductance sensors (Fletcher et al., 2010) and an ear-mounted heart rate sensor (Poh et al., 2010). A LED-vibrotactile device, *MiniHeart*, provides multimodal awareness of heart rate trend. A visual perceptual study of MiniHeart is included. A real-time screen display software interface, *Physioboard*, provides visual reference of the heart rate trend. This toolkit is deployed as real-time physiological displays in a laboratory setting for validating its usage, helping the ASD participants to communicate their inner states.

To investigate the in-depth, individual-driven approach, I start as an ethnographer to observe and to generate hypotheses with a non-conversational young man diagnosed with ASD and his mother. In this study, I hope to gain interpersonal understandings of the real-world situation where many misunderstandings may occur with missing information. This participant-driven approach will be covered as the home-based study in Chapter 5. This study is written as a confessional tale of ethnography (Van Maanen, 1988).

Table 1-1. The organization of this thesis

<table>
<tr><td colspan="4">Detecting misunderstandings
in both naturalistic and experimental environments</td></tr>
<tr><td>Interpretation</td><td colspan="3">Externalization</td></tr>
<tr><td>Rationale
Chapter 2. Three chosen approaches to understanding autism
Chapter 3. Investigating models of social understanding</td><td colspan="3">Toolkit
Chapter 4. Proposed technological tools for externalizing physiological arousals</td></tr>
<tr><td>Studied Perspectives</td><td>Arousal analysis tools (offline analysis)</td><td>Screen display tools (real-time)</td><td>Attentive feedback tools (real-time)</td></tr>
<tr><td>The home-based, participant-driven study
Chapter 5.
Location: A family, MA
('08 winter – '09 summer)</td><td>How can evidence of arousals (e.g., skin conductance) be used in everyday life?</td><td>How can videos help researchers to discover hidden characteristics?</td><td>Interactive video techniques were used to construct special channels of resonance.</td></tr>
<tr><td>A lab-based, experimental-driven study
Chapter 6.
Location: The Groden Center, RI
('09 spring and summer)</td><td>How can evidence of arousals (e.g., heart rate, skin conductance) be tracked and analyzed?</td><td>How can screen-based arousal information (heart rate) help caregivers to interpret arousal states?</td><td>How can real-time embodied arousal (heart rate) information help?</td></tr>
<tr><td>The school-based, clinically-driven study
Chapter 7.
Location: The Giant Steps, CT
('09 spring and summer)</td><td>How can evidence of arousals (e.g., skin conductance) be utilized to help the OT practice?</td><td colspan="2">Real-time applications are not covered in this study.</td></tr>
</table>

The lab-based study described in Chapter 6 investigates how class teachers estimate their students' arousal states with different kinds of physiological displays during the progressive muscle relaxation exercise (Groden et al., 1994). Physiological data were represented to the teacher participants in real time via a screen-based display and a LED tactile display in order to estimate their students' arousal conditions.[4] This lab-based study utilized a single-case experimental design (Kazdin, 1982) with direct replication to investigate one of the daily routines, the progressive muscle relaxation at a special education school. The experimental procedure consisted of a starting and ending baseline and three verbally guided phases with randomized physiology-display interventions followed by rest phases. This experiment is not intended to study the efficacy of the progressive muscle relaxation. This experiment presents, first, the quantitative analysis of the agreement rate of the teacher's estimation trend (i.e., the interpretation) and the student's heart rate trend (i.e., the externalization); second, the qualitative analysis of individual characteristics of the arousal trend across different experimental phases.

The school-based study presented in Chapter 7 documents the iterated observations of deploying physiological tools in a school-based occupational therapy curriculum with an occupational therapist (OT) and three teenaged, non-conversational students with ASD. This study investigates how the physiological tools could help the OT to interpret students' arousal states. This study intends to minimize the modification of the original OT practice in order to preserve its therapeutic function. During the iterated observations, a real-time interactive indexing tool, Interactive Physioboard, was implemented to reconstruct the context of a session using the collected data (e.g., image snapshots, behavioral events, physiological data). Interviews were done using this tool for generating qualitative data (e.g., the OT's estimation of student arousal, comments on situations, and insights of the sessions). Quantitative analysis was applied to study the correlation of the OT's estimation versus students' skin conductance data and to investigate arousal changes in-between behavioral events. A series of quantitative and qualitative analyses were applied during the study in an iterated manner. This study does not intend to evaluate the OT practice; neither does it cover the efficacy of each sensory integration therapy activity. This study focuses on the iterative processes of the OT's interpretations with the assistance of physiological tools. This study can be an exemplar of a strategic process of verifying and updating interpretations with in-situ data (e.g., student's arousal, behavioral events, OT's comments).

Lastly, I conclude the three studies by presenting a model of detecting misunderstandings that conveys the strategic processes of externalizing, interpreting, and detecting and updating biased hypotheses. I hope my readers can be empowered with this model in discovering misinterpreted situations via a reflective communication channel with people who are diagnosed with ASD or are non-conversational.

[4] This study assumes the caregivers optimally use their knowledge with available information to evaluate students' inner states.

1.3 Roadmap

The roadmap of this dissertation includes:

1. **This dissertation develops a practical method of externalization that detects misunderstandings** via physiology tools in order to strategically update the interpretations of individuals diagnosed with ASD, through three studies— a **home-based** study (N=1), a **lab-based** study (N=5), and a **school-based** study (N=3). The three studies investigate both the participants' externalization and their caregivers' interpretations.

2. **This dissertation presents a framework of social misunderstanding** to empower caregivers and autism practitioners to collect more information of externalization (i.e., arousal data are important references and can be comfortably collected via wearable wireless sensors) to minimize biased hypotheses or incorrect attributions of behaviors in their daily practice.

3. **This dissertation demonstrates Externalization Toolkit as novel ways to help communicate autonomic arousal states.** Physiology sensing and visualization technologies are integrated to provide intuitive references of participants' arousal states. MiniHeart and Physioboard, developed based on physiological sensors that measure heart rate and skin conductance data, are introduced to investigate hidden stressors as a means to unveil a detailed relationship between arousal and behaviors.

4. **The home-based study** presents an in-depth case study where I return to Kanner's perspective of documenting fascinating peculiarities. I present an ethnography of misunderstanding in a family with a young man (N=1, non-conversational ASD), documenting the processes of establishing a dialogue with him based on hypotheses that are frequently updated when any feedback occurs.

5. **The lab-based study** (N=5, ASD) presents findings on individuals' arousal characteristics with possible misinterpretations and an exploration of how caregivers estimate students' arousal with the assistance of physiological displays.

6. **The school-based study** presents an iterated observation collaborating with an occupational therapist (OT) and three teenaged participants (N=3, non-conversational ASD). Quantitative and qualitative analysis are applied with physiological tools for assisting the OT to characterize arousal events with overt behaviors.

Chapter 2

Background

Many interpretations have been made for explaining the unusual behaviors from people diagnosed with ASD. This chapter starts with a brief history of interpreting autism (section 2.1) then focuses on three chosen approaches: individual difference, clinical-driven therapy, and evidence-based research (section 2.2). A method of single-case experimental design is proposed to study the relation of interpretation and externalization (section 2.3).

2.1 Interpreting Autism

Common understandings of autism usually come from how autism appears and how it causes uncertainty in people's ordinary lives. If we hear a young man *has* autism, the label creates a series of images and expectations of how he might appear. The label itself distances us from a human being and tells us communication with the young man will be difficult and our efforts may not have the typical return. When seeking solutions to remove or to correct the appearance that autism brings, this young man's parents might have missed chances to learn who he *is*.

The conception of autism has been evolving since child psychiatrist Leo Kanner

(1943) and pediatrician Hans Asperger (1944) described the syndrome of autism as *affective disturbances* to children's social behaviors.[5] As the causes of autism were unknown at that time, doctors and psychiatrists could only come to *agreement* on how autism appears outwardly as syndromes and on the kinds of behaviors that are considered as ill behaviors.

The agreements regarding autistic behaviors have been evolving too. The Diagnostic and Statistical Manual of Mental Disorders (DSM) (APA, 1952) first included autistic-like symptoms under the labels of "Schizophrenic reaction paranoid type, Schizoid personality, and Schizophrenic reaction childhood type." In DSM II (APA, 1968), the description of "autistic-like symptoms" only appeared in "Schizoid personality" and "Schizophrenic reaction childhood type." The description of "autistic, atypical, and withdrawn behaviors" was updated into the label of "Schizophrenic reaction childhood type." In DSM III (APA, 1980), "infantile autism" officially became a category of mental disorder, where six symptoms needed to be present to receive the diagnosis. In 1987, DSM III officially made "autism" a category without the condition of infantile. Since 1994, DSM IV (APA, 1994) has provided the standard of diagnosing autism that an individual must present six out of sixteen symptoms to meet the diagnostic criteria.[6] According to Centers for Disease Control and Prevention (2006), one child in every 110 was diagnosed with autism. This institutional thinking, with generalizations based on a large group of samples, has been evolving into a major part of the culture of autism.

In contrast to the categorical explanation of autistic syndromes, this dissertation proposes an interpersonal approach to formulating and accumulating understandings by collecting information of externalization.

2.2 Hybrid Approaches to Autism

Since the 1950s, many efforts have been made to explain the *causes* of autism by psychologists, psychiatrists, neurologists, and genetic researchers. Others seek solutions (i.e., cures) for autism because autism has caused a significant impact on the mental and financial resources of families, schools, and institutions while still not providing satisfactory opportunities for the person with the diagnosis. I choose three approaches to understanding autism: individual difference, clinical-driven therapy, and evidence-based research, as shown in Figure 2-1. The individual difference approach typically occurs at home with limited samples. Clinical-driven therapy occurs at special education schools or institutions, and evidence-based research takes places in laboratories or controlled environments.

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[5] The word "autism" was used to describe "withdrawal" and was first introduced by a Swiss psychiatrist, Eugen Bleuler, in 1911. Bleuler is known for his pioneering work in schizophrenia.

[6] Receiving the formal diagnosis becomes crucial because families with autistic children can receive benefits and protections by law, especially when a full-time caregiver is required to accompany them. On Aug 3, 2010, Massachusetts Governor Deval Patrick signed the House Bill 4935 requiring private health insurance coverage for ASD, including evidence-based behavioral health treatments. Massachusetts is the 23rd state to pass this law.

2.2.1 Individual Difference. This approach emphasizes individual difference and often is used to report special conditions by parents, caregivers, and psychiatrists. They pay attention to in-depth understandings of individuals' characteristics. Stories are typically self-reported or reported by caregivers about daily experience, life styles, and cognitive and behavioral styles.

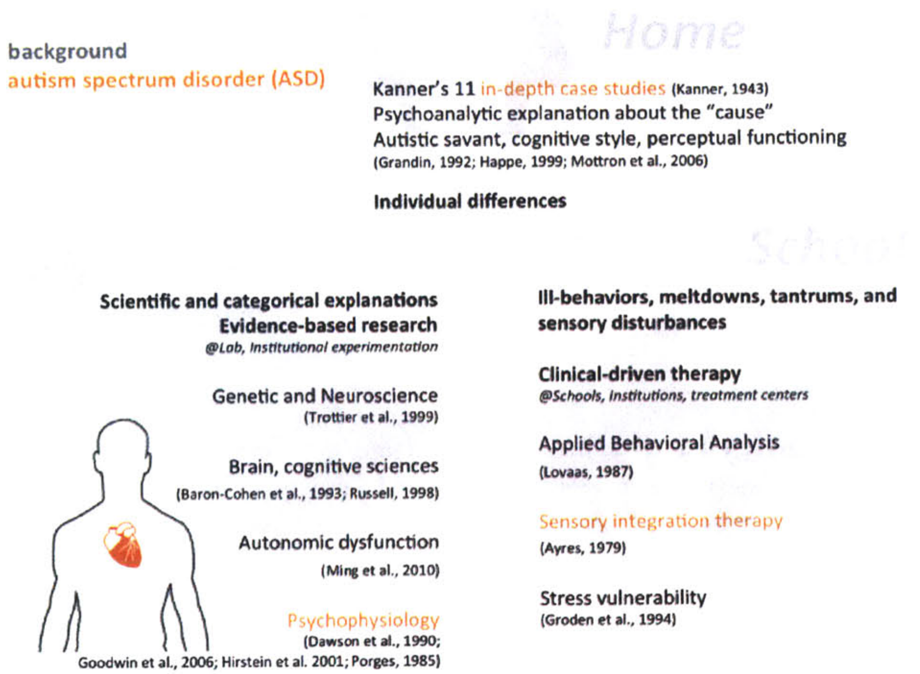

Figure 2-1. Three approaches are chosen to understand autism: individual difference, clinical-driven therapy, and evidence-based research.

Most early reports of autism were case studies describing the child's behaviors and his/her environments (e.g., Kanner's eleven cases in 1943). Some case studies were conducted as interviews in the psychoanalytic tradition established by Sigmund Freud. In the 1950s, psychoanalysis was a popular method of tracing underlying causes of autism via conversations. At that time, most people believed the cause of autism was related to the effects of the *refrigerator mother*, a psychological term referring to a mother who is too emotionally distant from her child and causes the child to become withdrawn. Around the 1960s, the Freudian and the psychoanalytic approach were discredited with regard to autism when evidence showed no scientific connection between refrigerator mothers and autism.

Most case studies' methods and procedures cannot be replicated, and results are not generalizable. However, some of them describe individuals' responses to daily problems and explain how they find their own solutions. In contrast to seeing autism as a kind of disease and seeking cures, some communities in recent years have started social movements (e.g., Autism Acceptance Project and Autistic Self-Advocacy Network[7]) trying to re-think the relationship between people with autism and society, and how society could pay attention to autistic people and their specialties. For example, some people with autism, "savants," are reported to have special abilities related to memory, arithmetic, and perception. Not until the 1990s did scientific discoveries start supporting the explanation of special cognitive characteristics of people with ASD. A more "local information processing style" appears in people with ASD and related conditions (Happe, 1999). Cognitive tests and studies have been revealing unusual information-processing characteristics in people with ASD. Some tests report them as deficits, while other researchers report them as styles or, in some cases, as advantages (Mottron et al., 2006).

In Chapter 5, I take the individual difference approach and focus on my understandings of a non-conversational young man's characteristics and relationships to his environments (e.g., preferences, habits, reactions to daily events). I conduct a home-based study in order to return to Kanner's perspective of seeking fascinating peculiarities in individuals.

2.2.2 Clinical-driven Therapy. *Meltdowns*, extreme "over-aroused" negative emotional conditions with undesired behaviors, often occur in autistic individuals' daily lives, sometimes without noticeable precursors. Meltdowns are usually considered as the outcomes of exceeding one's sensory capacity. Special sensory styles are reported to cause disturbances to behaviors (Bergman & Escalona, 1949; Grandin, 1992; Happe, 1999; Kanner, 1943). The early solution to these eccentric behaviors with autism was to institutionalize these individuals. In the 1970s, the standard of treating autism as a kind of mental disorder with difficult behaviors became widely accepted, since autism became a sub-group of schizophrenia described in DSM II (APA, 1968). When autistic children no longer got accepted in mainstream school classes because of their atypical behaviors, parents were eager to find a solution. Most parents would follow their doctors' suggestions, and some sought help from experienced communities. They received commercial messages that claimed to have effective ways to treat symptoms of autism. When there was a behavioral intervention program claiming to have effects on autistic children, those parents expected their children to be cured by those programs. However, all too many of these proposed courses of action lacked solid scientific foundations. Herbert et al. (2002) states, "The reason why autism is fertile ground for pseudoscience is because parents are highly motivated to attempt any promising treatment."

Behaviorists took an approach that became popular because the correction of behaviors appeared to be effective for a period of time after an "educational program." Behaviorists considered that problematic behaviors could be taught and be corrected with behavioral modification, based on reward and punishment, in operant conditioning that was used to change problematic behavior. A reward was provided when the child

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7 The Autism Acceptance Project (taaproject.org) and the Autistic Self-Advocacy Network (autisticadvocacy.org) represent positive rhetoric for individuals' specialties, in contrast to Applied Behavioral Analysis (ABA), which focuses on the negative part of behaviors.

followed the instructions. Applied Behavioral Analysis (Lovaas, 1987) stemmed from clinical institutions claiming experimental results proving effective influences on participants' socio-emotional behaviors. Lovaas reported that behavioral modification was the most effective way to educate autistic individuals to act normally in a two-year intervention. However, the validity of Lovaas's study is challenged by subject selection and outcome measurement (Gernsbacher, 2003; Smith et al., 2001).

With more cases of sensory-related issues reported, special educational programs emerged in order to accommodate students who are not tolerated in typical school classes as well as providing educational and therapeutic activities in a school-like setting. Sensory Integration Therapy (Ayres, 1979) focuses on sensory-arousal conditioning via a series of activities related to different stimuli of sensory inputs and to ways of regulating one's arousal. Sensory integration therapy, as part of occupational therapy (OT), has been widely accepted by parents as a behavioral and educational program for people with ASD, even though its therapeutic efficacy is still controversial and questioned by the scientific community (Baranek, 2002). For example, DIR/Floortime is a combination of sensory-motor and family activity for shaping empathetic, creative, reflective, and healthy peer relationships (Greenspan & Wieder, 2005). This family-oriented approach with active parents could provide intensive early intervention to young autistic children in order to shape their socio-emotional skills. However, as Greenspan and Wieder described in their paper, their investigation was not intended to demonstrate an effective outcome from the DIR model, but to highlight the importance of a family and relationship-based approach. Rogers and Ozonoff (2005) explain that a lack of methodological standards results in relatively few controlled studies on the efficacy of various behavioral interventions related to treatments of sensory impairments (e.g., sensory integration therapy) for people diagnosed with ASD.

In this dissertation, I conduct a clinical-driven study in a school-based occupational therapy curriculum. In this study, I investigated how physiological tools might help in the practical way with both quantitative and qualitative analysis in an iterated manner.

2.2.3 Evidence-based Research. A great deal of scientific effort to understand autism has been devoted to genetic research, cognitive sciences, and neurology. Genetic research and twin studies identified certain genes that may contribute to the etiology of genetic disorders related to autism (Rodier, 2000; Trottier et al., 1999). Baron-Cohen et al. (1985/1993) present a classic "false belief" test to discriminate an autism group from a mental retardation group and a control group. The ability to execute higher-order thinking, such as planning and controlling actions, appears often to be a deficit in people with ASD (Russell, 1998).

Autism is also considered as a stress disorder (or stress vulnerability) within everyday situations (Baron et al., 2006; Groden et al., 2005; Selye, 1956). Stress is highly related to autonomic dysfunction that produces increased blood pressure and heart rate and may both cause and be caused by sleep problems, gastrointestinal reflux, and bloating as well as psychological issues, such as anxiety and depression (Ming et al., 2010). Physiological arousal can be traced and measured from the activities of the autonomic nervous system (ANS) (Matsumoto et al., 1990). As shown in Figure 2-2, the ANS, one of the peripheral nervous systems, manages immediate physiological responses to predators or urgent situations. Within two branches of the ANS, the sympathetic nervous system stimulates the body to face the urgent situation as a fight-or-flight response that increases the heart rate and also stimulates sweat glands. The parasympathetic nervous system balances the body back to a normal state (e.g., lowers the HR). When there are increasing sympathetic nervous system activities, researchers have characterized them as increasing physiological arousal.

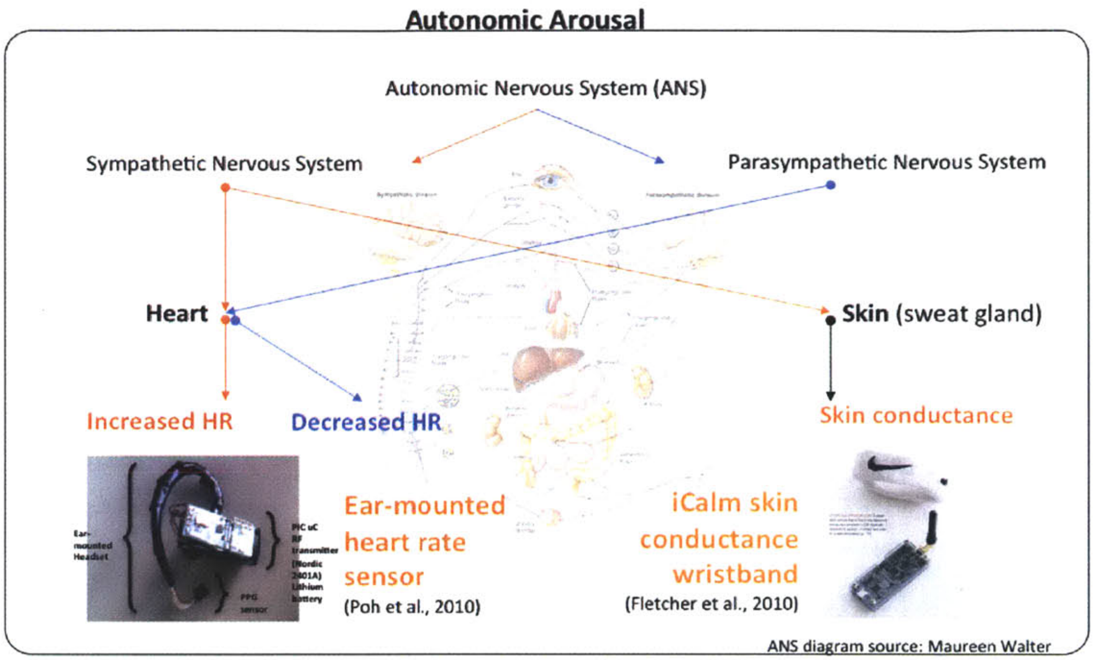


Figure 2-2. Physiological sensors are used for characterizing autonomic arousal states.

A growing number of researchers have been using physiological measurements to characterize inner states (Boccia & Roberts, 2000; Critchley, 2002; Hirstein et al., 2001; Liu et al., 2008; Schoen et al., 2007). Heart rate is also understood as an active indicator for measuring stress response in the autonomic nervous system (Goodwin et al., 2006; Porges, 1985). With advanced technology, ANS states can be represented as a way to understand stress and to provide personalized feedback (Picard, 2009). At MIT Media Lab, the Affective Computing Group has developed wireless physiological sensors that participants can wear during their daily activities. Several software and hardware interfaces have been built based on the ear-mounted heart rate sensor (Poh et al., 2010) and the iCalm skin conductance sensor (Fletcher, et al., 2010). In this dissertation, I build a set of physiological interfaces based on heart rate and skin conductance measurement, making the Externalization Toolkit described in Chapter 4.

This dissertation takes physiological sensors and the Externalization Toolkit into real-world conditions where participant's movements are less constrained by wires and equipment.[8] I collect physiological data from a more naturalistic setting. First, I conduct a lab-based study where I can investigate one of the daily routines at a special education school with physiological measurement in a controlled environment. In this controlled environment, participants wear wireless sensors while doing a familiar routine with their familiar class teacher, described in Chapter 6. Second, a school-based study covered in Chapter 7 deployed wearable sensors in a school-based occupational therapy curriculum. In these two studies, I applied quantitative analysis of physiological measurement as well as conduct qualitative investigations to understand a detailed situation about how the participants respond internally and how technologies could help communicate their internal states, especially when some participants are non-conversational.

2.3 Single-Case Experimental Design

Single-case experiments are often used in investigating behavioral interventions, because randomized experiments are less feasible for a small sample, and variations of psychological processes within individuals may not be obtained or generalized from a large-size sample experiment (Kazdin, 1982; Molenaar, 2004; Wolery & Harris, 1982). Kazdin (1982) describes single-case experimental design as a systematic way to study an individual intensively over a period of time as a supplement to studying groups. In single-case experiments, popular tools for assessing behaviors are frequency counts, categorization, and self-report/parent-report scales or questionnaires during baselines and interventions. Inter-observer agreement is usually required for assessing the quality of behavioral assessment when rated by human observers. An ABAB design refers to alternated conditions of baseline (Phase A) and intervention (Phase B) in a single-case experiment. A typical way of evaluating changes from Phase A to Phase B is to evaluate measured data for changes in mean, trend, and variation. This dissertation applies single-case experimental design in the lab-based study (Chapter 6) and the school-based study (Chapter 7).

The lab-based study utilized a single-case experimental design. This is an investigation of studying both the teacher and the student at the same time: first, how class teachers interpret their students' arousal states; second, how the participants respond internally to the experimental conditions of a daily routine taken into a controlled environment. Additionally, I investigated how arousal information could assist caregivers to estimate participants' arousal states during the Progressive Muscle Relaxation. This experiment consists of the following 7 phases: 1. baseline (2min), 2. guided relaxation with intervention 1 (2min), 3. rest (1min), 4. guided relaxation with intervention 2 (2min), 5. rest (1min), 6. guided relaxation with intervention 3 (2min), 7. baseline (2min). During the baseline phases, the student is asked to sit quietly for two minutes. During the guided relaxation phases, the teacher leads the relaxation while receiving physiological displays as interventions. Students are blinded to the teachers' experimental conditions so that students are not distracted by physiological displays.

The school-based study utilized a single-case experimental design in a caregiver-

[8] Physical restriction from the experiment could cause participants to react differently.

guided activity (i.e., occupational therapy sessions). I collaborated with a therapist to observe and study the process of occupational therapy with students with ASD. An occupation therapy (OT) session typically consists of a series of activities. The occupational therapist leads the sequence of activities differently each time depending on how the participant responds. Our participant wore a sweatband embedded with a wireless physiological sensor. Physiological data were collected in each OT session. Each session had different durations. However, each guided activity had a clear goal in order to stimulate or calm the participant's sensory experience. For example, jumping on the trampoline is a way to stimulate the participant's arousal with physical activity, while brushing arms and feet is a way to calm the participant as well as stimulate the tactile sensory input in a preferable way. After each observation, I defined different behavioral events as phases. During therapy sessions I observed, there were 8 to 14 phases with different lengths defined by the behavioral events, as a variation of an ABAB design. I was curious to understand how the participants reacted internally to the OT session as well as how the therapist interprets her participants' arousal states. When breaking down the original complete session into smaller phases, we are able to focus on each behavioral event with physiological analysis that presents changes in mean, slope, and variation of arousal (e.g., skin conductance data) as a way to understand the participants' arousal states. Physiological measurement is also presented to the therapist in order to have her feedback about her interpretation of the arousal state with and without the measurement data. In an iterated manner, this study attempted to understand the real-world constraints of using physiological measurement and how to improve this technology in order to assist the therapist to understanding one's arousal states.

2.4 Summary

Can an experiment be done in everyday life to understand the sensory disturbance as well as the individual? I plan to apply single-case experimental design in order to *debug* the understandings of sensory capabilities and autonomic nervous system states. As Hacking's investigation of the Multiple Personality Disorder, he says, "We need to go beyond symptoms, and hence beyond the *DSM*, to settle a reality debate. We feel more confident when we are able to intervene and change it" (Hacking, 1995 p.12). Every minute, while scientists are pursuing more knowledge about autism, parents and caregivers might be feeling lost when various kinds of information (e.g., news, medicines, treatments, journal reports, tales) are presented to them. Understanding autism remains a complex problem today. In reality, many real-world problems such as sensory disturbances occur repeatedly in families and schools. When most problems are treated as ill behaviors or accidences, the real reasons for causing stress are hidden and sometimes misunderstood.

The goal is to find a way in which parents and caregivers can directly benefit from investigations of their own daily lives. By acquiring more scientific evidence of their own life situations, parents and caregivers are empowered to keep their minds open to possible alternative solutions to autism, as well as discovering who their children are, without applying labels, such as being "autistic." Chapter 3 presents a theoretical investigation on modeling social understandings between caregiver and an individual.

Chapter 3
Modeling Social Understandings

Social understanding requires two-way communication between persons. In this chapter, I review several related theoretical models in order to characterize the process of how two persons construct social understandings. I will start from modeling communication (section 3.1), modeling (other's) inner states (section 3.2), and modeling supportive interaction (section 3.3). I will summarize these models and present a model of detecting misunderstanding (section 3.4). This chapter covers conceptual discussions of these models. More detailed mathematical discussions are needed, but beyond the scope of this research.

3.1 Modeling Communication

What is communication? Shannon (1948) provides a model of a communication system as shown in Figure 3-1. This model has been playing a fundamental role in the area of information technology. This model consists of five parts including: an information source, a transmitter, the channel, the receiver, and the destination. To understand this model in the context of social communication, we can think about a common social situation where two persons (e.g., Andy and Ben) are having conversations. Assuming they share the same language and communication skills, the subject that Andy expresses verbally can be understood by Ben completely. According to this model, Andy is the information source who expresses this message in a spoken way. When Andy speaks, he becomes the "transmitter" and his words, gestures, and voices are signals. Ben's ears and eyes mainly manage to receive the signals from Andy as the "receiver." Ben's brain reconstructs these signals (based on the shared language, experience, and communication skills) into a message to Ben's mind, which is the destination. When they are face-to-face in a quiet room, Ben is able to clearly hear what Andy talks about, but Ben might miss a couple of words when they are using a phone with bad reception that corrupts the original signal. The bad reception is captured in this model as a noise source affecting the channel transmission.

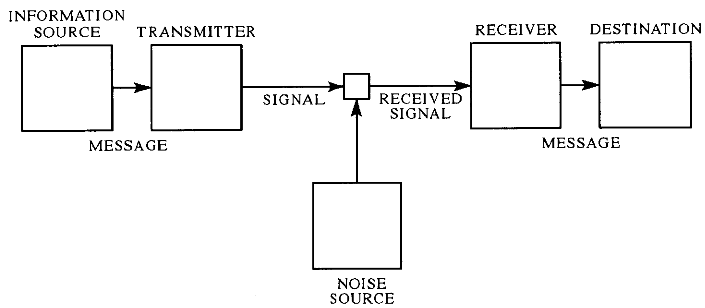


Fig. 1 — Schematic diagram of a general communication system.

Figure 3-1. A general communication system by Shannon (1948, pp. 2)

Wood and Hollnagel (2005) extend Shannon's model to represent a two-way communication—a dialogue, as shown in Figure 3-2. We can also extend the previous example of Andy and Ben's conversation here. After Ben receives Andy's message, Ben thinks about the meaning and goal of Andy's message. The process in Ben's mind is the "internal processing" described in Wood and Hollnagel's model.

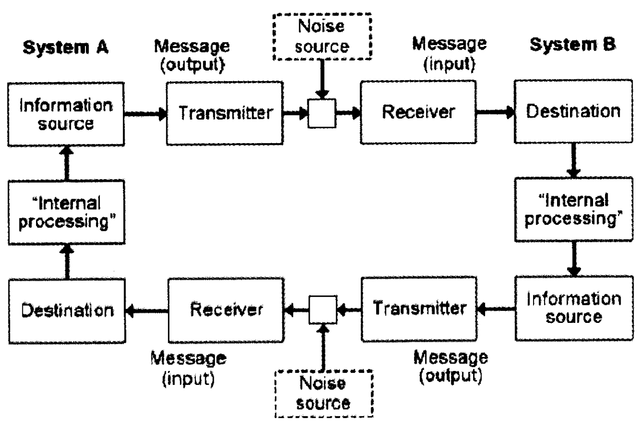


Figure 3-2. The extended two-way Shannon-Weaver model by Wood and Hollnagel (2005, pp. 13)

We can imagine a situation of this two-way communication when they are using a video conferencing system, but suddenly they lose the audio channel or they are in a very noisy place where they could not hear each other. In these two cases, Ben is not able to receive the verbal elements of this communication. The internal processing now functions in another way—guessing what each other means by how they behave, how they use gestures and facial expressions, or they find a piece of paper to write down the words.

We can also consider another condition where they do not share the same language and communication skills. In this Andy and Ben example, they might not understand the messages from each other. But they might smile or point to things to express their intention in a simplest way—using simple facial emotional expressions. This simplified way of communication via emotions is commonly used in people's daily life. When we see a person smile when she is chatting with friends, we receive the signal that she could be delighted and happy even though we do not directly talk to her.

In this Andy and Ben's example, social communication becomes difficult when they lose ways of communication. However, the alternative way emerges. They might start interpreting each other's inner states through non-verbal interaction (e.g., facial expressions, gestures). In autism, this can be further complicated by atypical expressions. In section 3.2, I will extend this discussion to related models that characterize inner states (e.g., emotions).

3.2 Modeling (Other's) Inner States

How do we understand another person? We usually start with what the other person might think. Baron-Cohen (1985) reports that people usually construct a small theory of what other people may think in order to understand the other's mind, the "Theory of Mind." [9] On the other hand, we often try to simulate their situations. When we fail to do this, people may think we are less considerate because we fail to simulate and take the other's feelings into account. Simulation Theory (Davies and Stone, 1995) suggests that people predict and infer what others may think based on how they would react in the same situation. People tend to simulate what could happen as a way to model the other person's inner states.

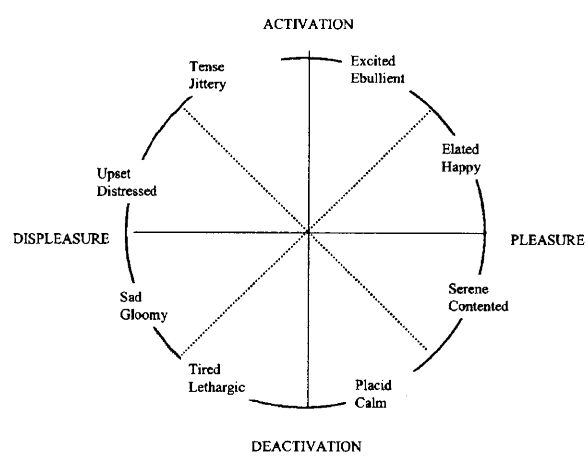


Figure 1. Core affect.

Figure 3-3. The core affect model by Russel (2003, pp. 148).

[9] Constructing a small theory about another person's mind is also known as "Theory Theory." Simulation Theory and Theory Theory are both considered "Theory of Mind." In Baron-Cohen's Sally-Ann false believe study (1985), children with autism showed they had deficits in constructing a theory to understand investigator's question.

Inner states can be considered as emotions, affects, or feelings. In this research, we will focus on the activation (i.e., strong or mild) and quality (i.e., positive or negative) of inner states. Russel (2003) presents core affect model that contains two major axes—arousal (y-axis) and valence (x-axis), as shown in Figure 3-3. Computational tools have been adopted to assist classifying human affects using statistical models (Kaliouby, 2005).

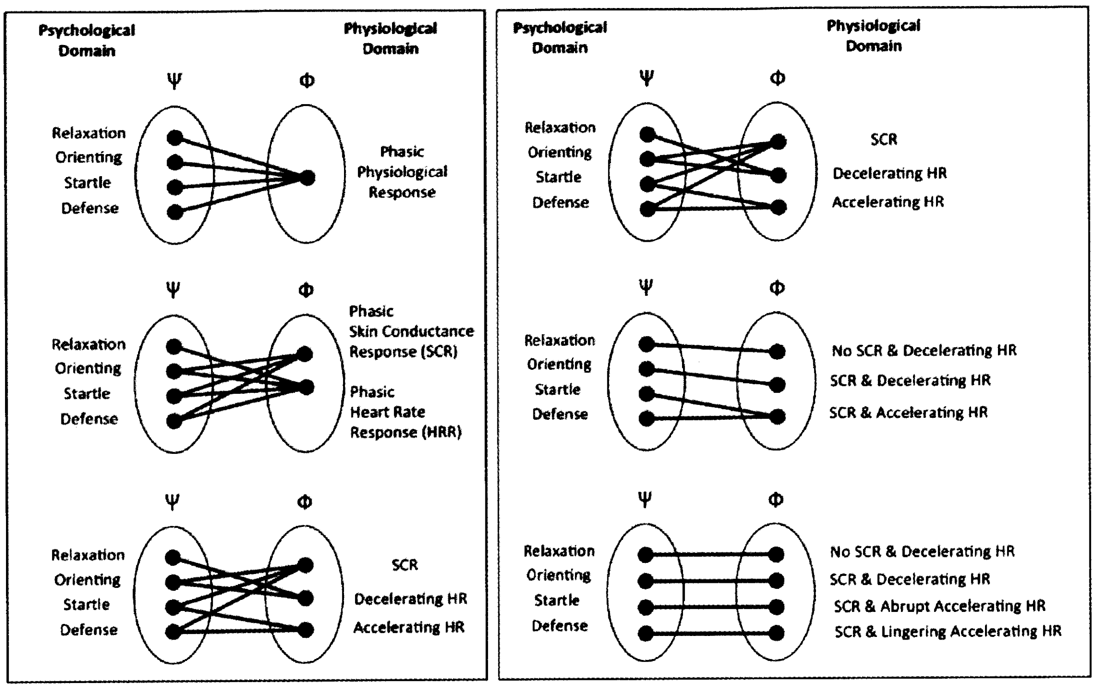


Figure 3-4. Mappings between psychological states and physiological states (Reproduced from Cacioppo and Tassinary 1990, pp. 22).

There are strong linkages between the states of human body (e.g., how aroused we are) and the inner states. Cacioppo and Tassinary (1990) present mappings of relationships between psychological states and physiological states, as shown in Figure 3-4. Psychological states such as relaxation, orienting, startle, and defense can be mapped into one-to-one relation. However, human affects are spontaneous, dynamic and highly context-dependant. The same facial expressions can be recognized as opposite affects when the identical faces were placed in different contexts (Aviezer et. al., 2008). For an individual, one emotion may only have a fixed meaning for a relatively short period of time. It is important to take both psychological states and contextual information into account for characterizing physiological states.

Behaviorists take a very different approach to modeling a person's behaviors based on reward and punishment conditions without modeling inner states. Skinner (1953) describes that "the consequence of behaviors may feedback to the organism" (pp. 59) as in the popular behavioral theory of learning with operant conditioning and behavioral reinforcement. Skinner's theory tends to ignore the inner states; however, how our body reacts does relate to the inner states.

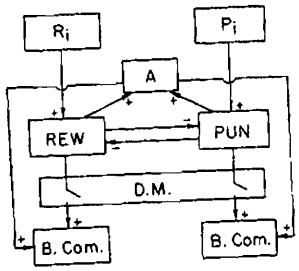


Fig. 1. The arousal-decision model adapted from Gray and Smith (1969). R_i and P_i: inputs to the reward and punishment mechanisms. REW: Reward CS mechanism. PUN: Punishment CS mechanism. A: the arousal mechanism. D.M.: the decision mechanism. B.Com.: behavior command to "approach" (on the reward side) or to "passively avoid" or "stop" (on the punishment side).

Figure 3-5. Fowles's three arousal models (Fowles, 1980. pp .90).

To extend Skinner's model to include inner states, in psychophysiology, Fowles's three arousal model (1980, pp.90) shows reward and punishment conditions trigger the arousal systems, as shown in Figure 3-5. Fowles's model consists of a behavioral activation system (BAS) for active avoidance, behavioral inhibition system (BIS) for passive avoidance, and a third arousal system triggered by both BIS and BAS activation. Furthermore, Fowles suggests the activation of BIS connects to the skin conductance activity, and the activation of BAS connects to cardiac-somatic activation such as heart rate increase. Fowles's research implies the connections between physiological measurement and behavioral states.

Interpreting behavioral events can be investigated based on arousal-behavioral and personality literature. Rubenstein and Fowles et al. (2000) described a positive correlation of fearfulness and activation of skin conductance (SC) activities. Merzenich (2003) suggests that an increased ratio of excitation/inhibition results in some forms of autism. One possible way from the technology side is to use motion sensors to rule out possible somatic-coupling BAS events (e.g., if there is too much motion, it could be a dynamic activity that contribute to a BAS event). In contrast, if there is not much motion but the SC data is actively showing tonic and phasic responses then that may indicate a situation where BIS is activated, meaning there are potential stressors in the environment. Based on contemporary neurological evidence[10] on BIS and BAS, Carver and White (1994) developed a BIS/BAS self-report scale in order to link behaviors to personality in order to address detailed individual differences. For a person with high-functioning BIS, s/he tends to be anxious and frustrated easily.

Skin conductance, heart rate, facial expressions, and other measurable signals can be used for understanding people's emotional quality (Picard, 1997). Continuously measuring a person's physiological information can be used to show possible trends of a person's anxiety. Combining physiological measurement with other measures about the

[10] In neurology, septohippocampal circuit functioning is related to anxiety disorder that connects to the theory of BIS (Gray, 1990).

situation may reveal how this person builds up his stress and anxiety from environmental stressors as a way of interpreting one's behaviors. Physiological information can be represented and designed as actuators in visual, tangible, and tactile ways according to a person's perceptual preference for him or his family to be aware of his physiological condition.

Studying how to interpret individual differences from the captured arousal and behavioral events is still new in this domain because there was little data collected in the real-world settings and there was no standardized method to validate this type of work. With a more mature understanding of the real-world context and more durable tools that could help collect reliable data, this approach of investigating real-world interaction could become crucial in unveiling more understandings about people diagnosed with autism in their daily lives instead of studying their responses under a laboratory setting.

3.3 Modeling Supportive Interaction

The goal for social understanding is to provide considerate support. Especially for people with difficulties communicating in typical ways, caregivers need to consider the whole situation. However, a situation often contains hidden elements that are not visible before they create stress for individuals. For fostering communication, Karasck and Theorell (1990) presents the Demand-Control-Support Model originally developed for analyzing work stress with peer supports, as shown in Figure 3-6 (left).

The Demand-Control-Support Model is a three-dimensional matrix- Demand, Control, and Support- that analyzes how work stress appears. Demand represents the requirements of the situation. A situation is "high-demand" if it requires significant mental, physical, or emotional resources to address it. For example, an autistic or non-verbal learning disabled person who has to individually interpret each facial movement in real time and reason about facial movement patterns explicitly while trying to simultaneously carry on a conversation will see face-reading as a high-demand task. However, for people who simply "intuit" facial expressions while conversing, it is a low-demand task. Control represents ways to have power or influence over the outcomes in a situation. When a person faces a situation where he has the ability to directly manipulate the outcome, we can say this is a "high-control" situation. A "low-control" situation usually makes a person feel helpless because he cannot influence the outcomes to happen in the way he wants.

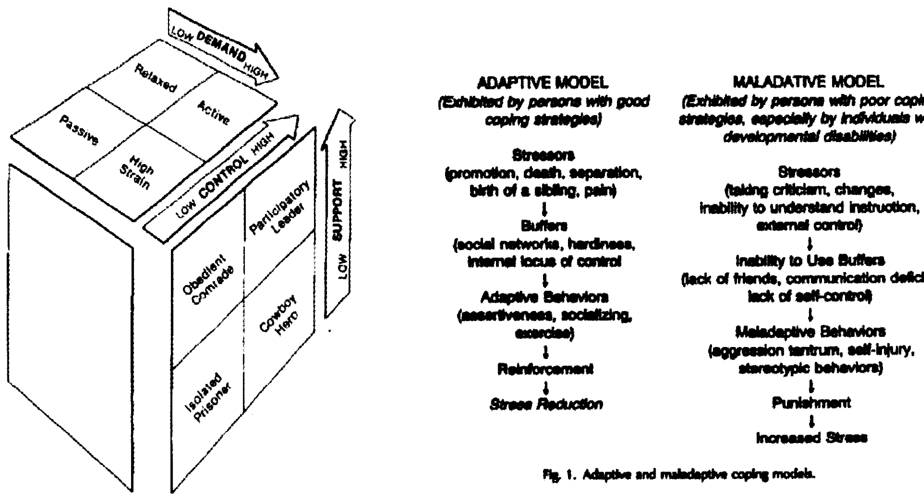


Figure 3-6. (Left) Demand-Control-Support Model by Karasck and Theorell (1990. pp. 70). (Right) Adaptive and maladaptive stress coping model by J. Groden (1994, pp. 184)

Support represents the communal resources for improving a situation for a person. A "high-support" situation means that a powerful community is able to actively assist the person for his problems. A "high-support" situation also represents a resourceful environment where people are skillful, active, and considerate of the needs of those around them, even if those needs are very different from their own. Disabled individuals often face "low-support" situations in which those around them misunderstand their needs and abilities, e.g., a problem with moving or speaking that may be intermittent, or when those around them act in ways that are not helpful or even harmful, e.g., bullying or treating as inferior. An autistic individual may often have difficulties in "low-support" situations where people who surround him do not clearly understand the situation or unable to actively give relevant supports.

Groden (1994) illustrates two stress coping models, as shown in Figure 3-6 (right). The adaptive model presents a successful coping strategy of stress where social support and adaptive behavior provide positive effect for stress reduction. However, for people with autism, their atypical behaviors are often punished and that can lead to a loop of accumulating stress. It is difficult to infer their inner states. At the same time, it might be equally difficult for them to communicate their stress.

Social understandings are never one-way communication. For people with autism, the typical ways of communication might not be adequate to understand their situations. To provide the best supportive interaction, caregivers need to keep alerted of possible stressors and sometimes these are hard to identify for a person who perceives the world differently. There are strong needs for helping each person to have reliable ways to communicate their inner states.

3.4 Summary

I present a social understanding framework that integrates models of communication, inner states, and supportive interaction, as shown in Figure 3-7. This framework consists of a caregiver and an individual with ASD, and four layers: theory of mind, information, arousal, and personality. The two-way communication occurs in the information layer (i.e., Shannon's communication model). The received messages guide each of them to construct a model of the other one (i.e. the theory of mind). During the communication, the arousal layer (i.e., physiological arousal that makes emotions stronger and more intensive) is interacting with the individual layer (i.e., personal traits and characteristics). For example, excitement about a toy increases heart rate. Typically, the arousal layer is resonating with a person's emotion and with the situation. However, for people diagnosed with autism, it is especially difficult to infer their inner states when outward signs are atypically related to inward states. Goodwin et al. (2006) found inconsistency of overt behaviors and cardiovascular arousal in teenagers. When the individual has difficulty to communicate or expresses over-aroused states in an atypical way, the messages between these two persons might be easily misunderstood.

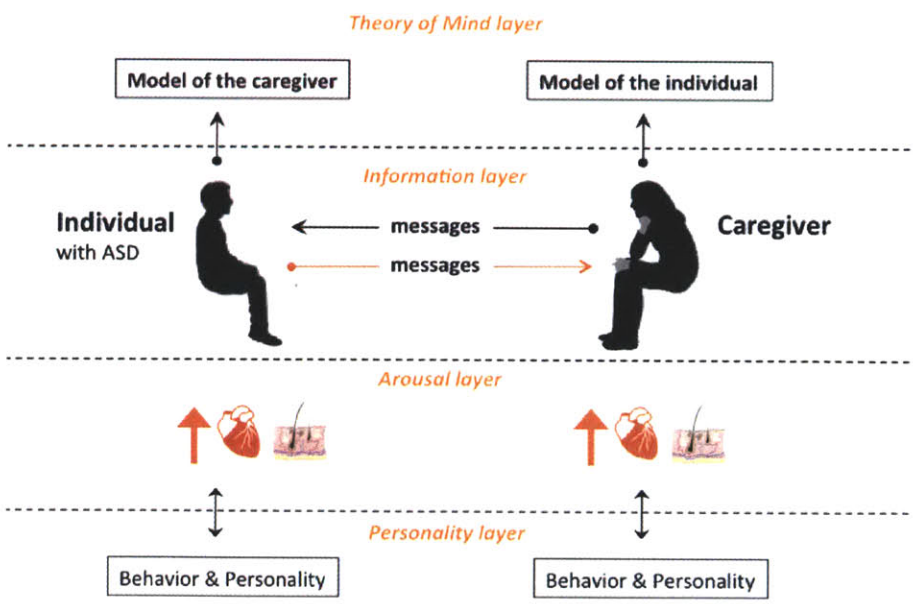


Figure 3-7. A multi-layer framework of social understanding.

To support an individual with autism, it is ideal not to miss any message from the individual, especially when some messages may be the pre-cursors of over-aroused behaviors. Let us consider an alternative framework where arousal layer merges with the information layer, i.e., arousal data can be transmitted as messages to the caregiver, as shown in Figure 3-8. When the caregiver receives arousal messages in addition to existing messages, this extra information helps the caregiver to update her hypothesis and the model of the individual so that a more precise interpretation can be made for supporting the individual.

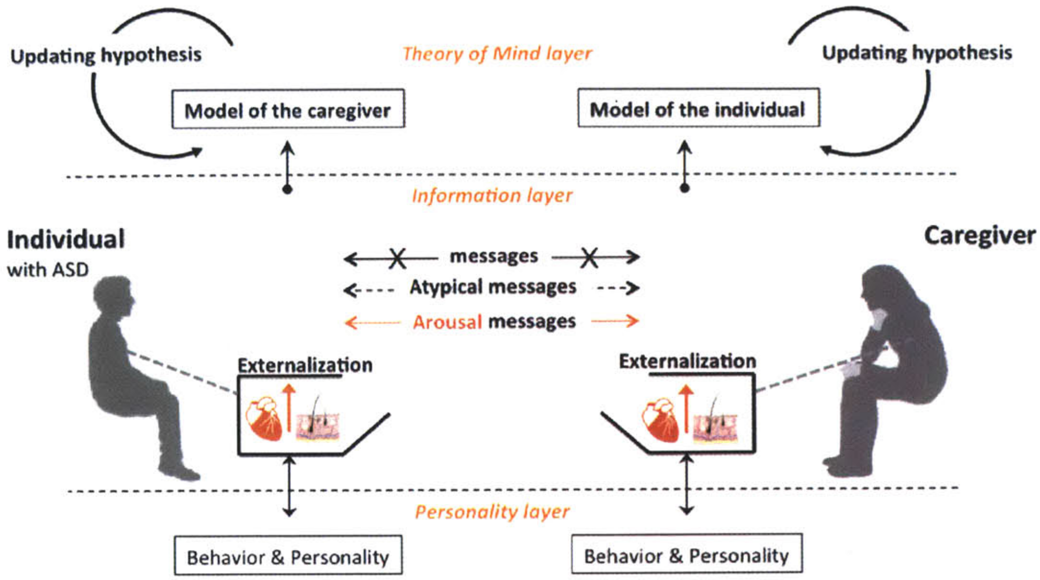


Figure 3-8. An alternative framework of social understanding—arousal data as message

Externalizing inner states (e.g., arousal) could help shift a "low-support" situation into a "high-support" situation. This thesis presents an alternative framework of social understanding where the arousal layer becomes a part of the information layer by externalizing arousal data, as shown in Figure 3-8. In the information layer, when the typical communication channel cannot provide enough information for social understanding, misunderstandings may occur. When an individual transmits messages in atypical ways, the caregiver might not understand what that means. For the individual, the caregiver could have been sending atypical messages because this individual is equipped with a different cognitive style, including possibly different perceptual abilities (Mottron et al., 2006). When externalization adds arousal information to the existing communication channel, both caregiver and the individual are able to update their mental model of each other in the theory of mind layer. In addition, information layer can be connected with personality layer when externalization reveals the linkages between arousal, behaviors, and personality. The concept of externalization becomes the prosthesis of the broken communication channel that could assist in re-constructing the original meaning of the message. Once the correct message is delivered, the feedback between the two individuals assists in developing shared understandings, which may strengthen their relationship.

When the processes of stress-buildup become transparent via physical representations and accessible to the individual and his or her family, this may enable new ways of generating a kind of communal knowledge about a person's capacity of stress. Parents, siblings, caregivers, teachers, and family doctors who interact with this individual are potentially able to understand more situations needed for supports. In the following chapter, I will present Externalization Toolkit, a set of technologies that help to observe, reflect, and communicate emotional moments (from physiological measurement) as references of social understanding.

Chapter 4

Externalization Toolkit

Characterizing inner states

Inner states of an individual with ASD are sometimes not observable or are ignored before he or she becomes overly aroused. A typical way to communicate inner states is to use a conversational language that minimizes misinterpretations. When this typical way becomes unavailable, physiological arousal can become an alternative to interpret the inner states. This research defines *externalization* as observable information that closely connects to inner states. Externalizations can be a specific behavior reflecting an inner state (e.g., flickering fingers could mean being anxious for certain individuals) or objective physiological measurement (e.g., heart rate, skin conductance).

This chapter presents a set of research prototypes utilizing physiological measurements to quantify and to help communicate inner states (i.e., autonomic arousal states) as externalization. Section 4.1 describes the MiniHeart, a LED vibrotactile device designed as a small, soft object synced to a person's heartbeat. Section 4.2 presents Physioboard, a physiological display interface used to display arousal trends visibly in real time. Section 4.3 presents an interactive arousal analysis tool for reconstructing the recorded situation. These tools are deployed in the three studies of this dissertation.

4.1 MiniHeart: An LED-Vibrotactile Device

The MiniHeart is a hand-held heart-shaped device that displays heartbeats, as shown in Figure 4-1. The intensity of the pulsing LED and tactile actuation maps to the bodily rhythm show as heartbeats that provide an illusion of an external heart. The MiniHeart wirelessly receives (12bit ADC 20Hz) the heart rate data from ear-mounted heart rate sensors (Poh et al., 2010) or Polar HR sensors,[11] and displays them via a pulsing white LED and vibration.

Figure 4-1. The MiniHeart is a hand-held heart rate indicator that wirelessly receives beat-to-beat heart rate signals and then represents them as pulsing LED lights and vibrations.

A scenario for a typically developed individual:

> Jack wears an HR sensor and puts the MiniHeart device in his pocket. He is in a rush to get to a meeting where he needs to present his work in front of a group of important people. In the elevator, he takes out the MiniHeart and is aware of his heart rate reaching 160 bpm, similar to the HR while he is exercising. He realizes his body is highly aroused. He takes some deep breaths. He exhales slowly to calm his body down. Before he enters the meeting room, he feels calm again, and the pulsing LED on MiniHeart slows down. He takes another deep breath and steps inside the meeting room.

In this scenario, this individual understands the basic mechanics of why his heart rate accelerates and how he is able to slow down his heart rate by taking long breaths. He is aware of how the MiniHeart relates to his bodily arousal. The MiniHeart becomes an external reference of his body. However, it may take some time for an individual to establish a trustworthy connection between his body and the technology. For example, if the technology is not reliable, he might abandon it before getting used to it.

A scenario for an individual who has difficulties in regulating autonomic arousal:

> Tom is diagnosed with high-functioning autism. His parents think his emotions are usually unstable in his everyday life. His parents learn from magazines and

[11] Polar heart rate sensors are commercially available wearable belt sensors.

Websites that his unpredictable behavior can be associated with his physiological states. Tom's father purchases a set of technological tools that contains a variety of wearable heart rate sensors (a belt sensor, wrist sensor, ear-mounted sensor, and other form factors) and a MiniHeart device. The father finds that the belt HR sensor works the best for his unpredictable son, because it won't easily get lost or fall off from his body. The MiniHeart device displays the son's heartbeats with small vibrations. The father puts the MiniHeart in his pocket so that he can feel the vibrating MiniHeart while watching Tom's activities (e.g., eating, playing, watching TV). The father realizes that Tom has a higher heart rate than he does. When Tom gets frustrated, his heartbeat rises very quickly before he gets angry.

This scenario illustrates how an individual and his community may be able to understand their daily interaction via a portable device. The device may benefit people who frequently observe the individual.

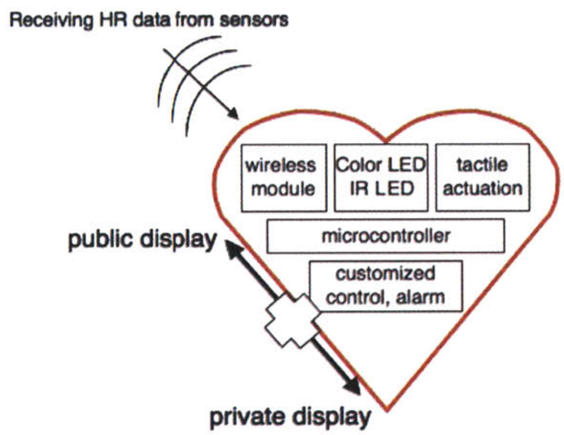


Figure 4-2. The MiniHeart, a wireless hand-held physiological indicator, is equipped with an adjustable display, ranging from a public display (color LED), to a semi-private display (IR LED, detectable by computer), and a private display (tactile actuation).

System Architecture. The MiniHeart is a wireless hand-held physiological indicator equipped with an adjustable display ranging from a public display (color LED), a semi-private display (IR LED, detectable by computer), and a private display (tactile actuation), as shown in Figure 4-2. The MiniHeart includes: 1) a wireless module for receiving heart rate data from wireless heart rate sensors, 2) a white LED for display pulsing heartbeats, 3) a color LED for a customized HR alarm, 3) a vibrating motor for tactile actuation, 4) adjustable controls to switch between different display modes, 5) a PIC microcomputer, and 6) Li-poly batteries (~4hr continuous usage).

The MiniHeart was designed to be a mobile device that resembled an external human heart with synchronized heartbeats. This device consisted of an acrylic heart-shape enclosure, a 250mAh lithium polymer battery, and a circuit board encased inside silicon-rubber (Dragonskin[12]). This circuit board was built as an extended development of Poh's heart rate earring sensors. It received HR signals via Nordic 2401A transceiver

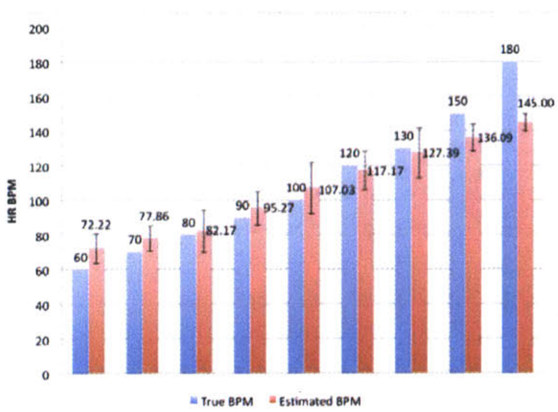
[12] Dragonskin is a kind of silicon-rubber.

(12bit ADC 20Hz). A small analog circuit converted the strength of the analog signals (PPG waveforms of heartbeats) to drive a white LED and a vibrator.

A visual perception study of the MiniHeart will be covered in the following section. In Chapter 4, I bring the MiniHeart into a controlled environment. In future works, tactile perception and biofeedback are other important topics to be studied. It is also important to study the MiniHeart in a more naturalistic setting. However, due to the current constraints of durability of the prototype (fragile electronics, battery life for a day-long observation, and ear-mounted sensors not suitable for teenagers' dynamic and physical activities), conducting studies for the MiniHeart in a therapeutic setting will not be covered in this dissertation.

Visual Perception Study.

Method. A perceptual experiment was conducted in order to understand how typically developed humans perceive the pulsing LED and estimate the heart rate it represents. A simple visual perception test consists of 10 visual tasks. Participants need to look at a pulsing LED that blinks at an unknown speed of 60, 70, 80, 90, 100, 120, 130, 150, 180 bpm. Each task lasts about 10 seconds. Participants need to estimate the BPM of this pulsing LED after each task, following a 10-second break. In the questionnaire (see Appendix A), they are able to circle a range of values for estimated BPM (e.g., 60-90 bpm, 110-120bpm, or 100-140 bpm). The mean of the circled values is used as participants' estimates. One example task at 60 BPM is given before the real study starts. A comparison between the true value and the estimated BPM is analyzed to see how accurately participants are able to rate beat-per-minute via visual perception. The accuracy of visual perception of changes in BPM trend is also calculated based on how well participants are able to detect an increased or decreased BPM trend in adjacent tasks. Two-sided Wilcoxon signed rank tests are applied to test the null hypothesis that the estimated BPM data matches the true BPM value. If the test rejects the null hypothesis at the 5% significance level, we describe it as having a statistically significant difference between true BPM and estimated BPM.



TRUE BPM	Estimated BPM: M	Estimated BPM: SD	Two-sided Wilcoxon signed rank test: p	Two-sided Wilcoxon signed rank test: Significance
60	72.22	8.44	0.00026	p<.05
70	77.86	7.26	0.0029	p<.05
80	82.17	12.14	0.4884	n.s.
90	95.27	9.50	0.0034	P<.05
100	107.03	14.69	0.008	P<.05
120	117.17	11.09	0.1211	n.s.
130	127.39	14.29	0.6486	n.s.
150	135.28	7.95	0.000035	P<.05
180	145.00	5.00	0.0039	P<.05

Figure 4-3. Comparison between average estimate of BPM and true BPM value

Results. Twenty-two participants (N=22, healthy adults) completed 22 trials. Each trial had 10 visual tasks. A total of 220 visual tasks were completed. A comparison between participants, as shown in Figure 4-3, illustrates that when true BPM values are 80, 120, and 130, estimated BPM values show no statistically significant difference. When true BPM values are 60, 70, 90, 100, 150, and 180, there are statistically significant differences between the estimated values and the true values ($p<.05$). Six out of nine estimated BPMs are significantly different from the true BPMs. Participants exhibited 33% accuracy when estimating an absolute value of BPM. This result implies that human perception might not be reliable when estimating the absolute blinking rate within 10 seconds. When comparing the accuracy of participants' perceptions of BPM changes (increased or decreased BPM), there are only 18 false estimates of BPM trend out of 198 trends. In other words, participants have a 90.9% accuracy in perceiving BPM changes. This result implies that humans have substantially accurate perceptions of increased or decreased BPM when it is viewed on the MiniHeart's pulsing LED.

4.2 Physioboard: A Real-Time Physiological Interface

Physioboard is a camera-based real-time physiological data representation tool, which served as a screen-based physiological display (for teacher participants) in the lab-based study (Chapter 6). Inputs include: 1) an ear-mounted HR sensor and receiver, 2) an iCalm SC sensor and receiver, 3) the data acquisition Python Program. Physioboard displays processed HR out of raw photoplethygraphy (PPG) waveforms from heart rate sensors (Poh et al., 2010) and computed skin conductance level (in microSiemens) from an iCalm SC wristband (Fletcher et al., 2010).

As shown in Figure 4-4, Physioboard plots the HR beat per minute (BPM) and a BPM trend over one minute on screen so that teachers are able to trace the HR trend visually. The BPM value is updated in real time. A Firewire camera (a Unibrain Firefly) captured 640x480 30fps image sequences and displayed them on Physioboard. This software superimposes the overt behaviors (from camera) with inner arousal (HR and SC) on one screen. For the user interface design, I intentionally overlay HR data on top of the captured camera video stream to allow teacher participants to keep their attention on the student in the camera view when looking at the screen. This version of Physioboard was written in Python 2.6 with OpenCV 1.1 and PySerial, to receive inputs from a Firewire Camera, iCalm SC sensors, and HR sensors.

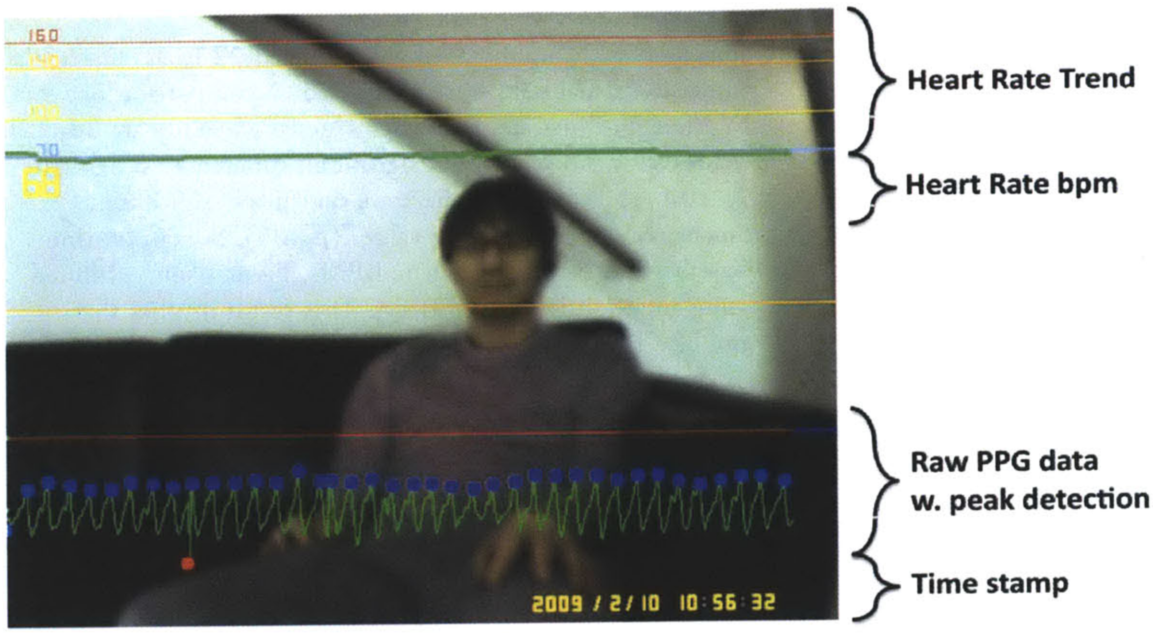


Figure 4-4. Physioboard displays HR BPM (bold green line), raw PPG waveform (light green lines), detected beat-to-beat intervals (blue points), and skin conductance level (orange line) superimposed over image snapshots.

4.3 Arousal Analysis Tools

Arousal analysis tools are developed for off-line investigation of physiological arousal. The goal is to provide an intuitive interface for practitioners to use this software to review the clinical therapy session. I extend the functionality of Physioboard (Section 4.2) into Interactive Physioboard that enables caregivers or therapists to index and rate synced images and skin conductance data dynamically. The main reason for building Interactive Physioboard is specifically for the therapist to review the data after the recording session. I use Physioboard (described in section 4.2) software to collect both physiological and image snapshot data. However, the original Physioboard lacks the ability to rewind quickly and replay because it was designed for real-time presentation. I found there is a need for combining intuitive indexing with synchronized physiological data and image snapshots.

Indexing interface. Interactive Physioboard, written in Processing,[13] enables users to intuitively index video snapshots with synced skin conductance data when moving the mouse cursor along the timeline. The interactive indexing function provides real-time response for its user to have a quick overview of what happened with the SC data and video snapshots. When a user clicks on the timeline, it automatically splits the timeline into two phases and plots lines for illustrating the mean value and +1/-1 standard deviation on the screen in order to automate some statistical needs. This indexing

[13] Processing language. See processing.org

interface is able to collect multiple tracks of data (e.g., both the therapist's and the participant's SC data), as shown in Figure 4-5.

Figure 4-5. Interactive Physioboard collects and processes two skin conductance inputs (the participant's and the occupational therapist's). The user can move the mouse along the x-axis to retrieve images dynamically at the specific time in an interactive way.

Estimation interface. When conducting interviews with the caregiver about the therapy session, I found there is a need for an interface to estimate how aroused the participant is from a therapist's point of view. The therapist is not given the true skin conductance values, but is asked to view the video snapshot data in order to estimate the participant's arousal and draw a line for the estimated arousal trend, as shown in Figure 4-6. The therapist is allowed to index back and forth to get the whole picture of the occupational therapy session, as well as remind themselves of what happened. I ask the OT questions about the situation. An audio recording function is used for keeping a record of the OT's comments. A separated R script is used to perform Pearson's correlation test in order to quantify the OT's estimation and the participant's skin conductance data. In future works, this estimation interface can integrate the audio recording and statistical analysis functions.

Commenting interface. Interactive Physioboard represents each OT session with video image snapshots, skin conductance data, and the OT's comments from the interviews. The commenting function allows other related caregivers[14] to leave comments on the same session. This accumulative function may create a rich repertoire of data when viewed and commented upon in a repeated manner.

[14] In the school-based study, only the OT and I commented on each session. However, it has the potential to be exposed to a closer community (e.g., the participants' family members, therapists, other familiar school teachers).

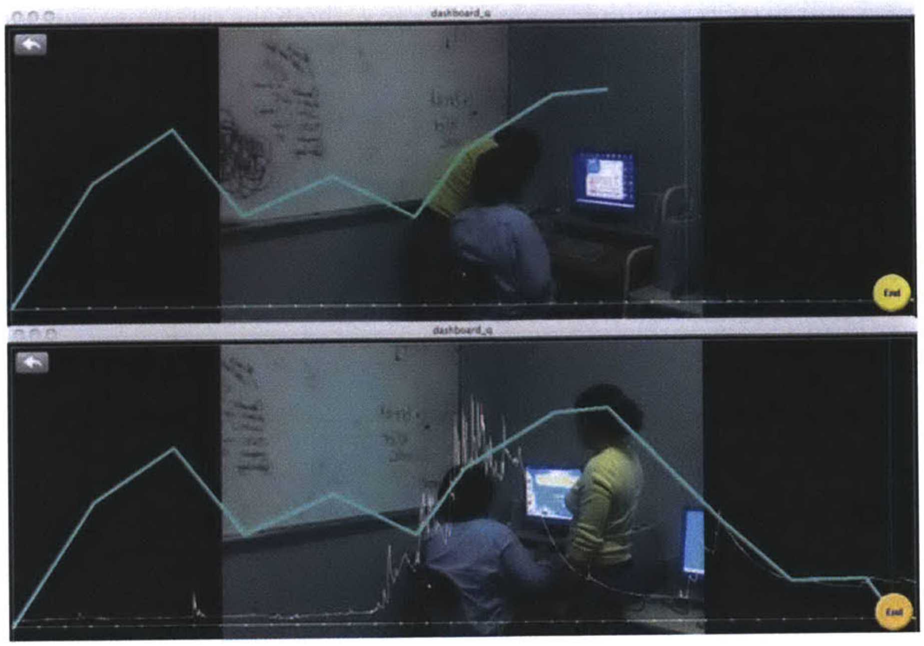


Figure 4-6. Interactive Physioboard is an arousal estimation interface. Caregivers are not given the true skin conductance value, but are asked to draw an estimation line of the arousal trend of the participant while the video replays the session.

Interactive Physioboard is a software prototype that evolves when accommodating new real-world usage. This software interface is part of the outcome of the school-based study where I attempt to deploy physiological tools under the clinical practice-occupational therapy.

4.4 Discussion

The goal for the Externalization Toolkit is to empower its users to perceive inner states intuitively. The rationale is to amplify the information (physiological data) that could be used as valid evidence for interpretations. This dissertation designs three kinds of tools for approaching towards this goal: the MiniHeart (section 4.1), Physioboard (section 4.2), and Interactive Physioboard (section 4.3).

The silicon-rubber version of the MiniHeart has a tactile feeling similar to the pressure ball (or stress ball) that individuals hold and squeeze when stressed. It is beyond this dissertation to study the MiniHeart as a stress-feedback (or biofeedback) tool for individuals with ASD. The MiniHeart may work for higher-functioning individuals, because they might have a better chance of understanding how it works. The MiniHeart presents itself as a physically recognizable copy of one's heart rate. For some individuals who are sensitive in responding to mechanisms, it is also interesting to see how these individuals might respond to mechanisms that are actually part of their own bodies. However, it has come to my attention that in 3~30Hz (180-1800bpm), the most dangerous frequency is between 15~18Hz) blinking lights may trigger photosensitive seizure (Topalkara et al., 1998). This did not occur in my participants, but further investigation will need to take this into account. According to interviews of special education schoolteachers, this device might help teachers to inspect students' internal states in a more unobtrusive way. In practice, the MiniHeart still relies on durable heart rate sensors that can be deployed in real-world situations.

Physioboard can be extended and utilized in the real world in several ways, including a mobile version of Physioboard that uses a camera and receives physiological data on smart phones, or a wearable version that uses head-mounted display (Mann & Niedzviecki, 2002). The challenging part for a real-time arousal display is how disruptive it could be, but it still opens up a channel for communicating arousal in non-speaking students.

For the arousal analysis tool, I find the most valuable part of Interactive Physioboard is the iterated processes. There are many ways to improve the interface design for each function (indexing, estimating, and commenting). The other important aspect for Interactive Physioboard is to be used repeatedly within the participant's support group (e.g., parents, caregivers, physicians). In future works, it will be valuable to observe how the support group uses it for exchanging ideas of understanding the individual.

The Externalization Toolkit should not be limited to prototypes illustrated in this dissertation. Many enhancements should be considered in order to deploy these tools in both controlled and naturalistic environments. I hope this chapter has provided a direction for tools that help to communicate inner states.

Chapter 5

The Home-based Study

A participant-driven approach

"Things gain meaning by being used in a shared experience or joint action."

John Dewey
Democracy and Education, 1916

This chapter seeks to return to Kanner's (1943) original perspective of discovering fascinating peculiarities in the first eleven cases of in-born autistic disturbance of affective contact. Three of them are non-verbal. The other eight children are reported as having the ability to name objects rather than to use language to communicate with others. One can imagine how easily someone who does not speak or respond in a normal way can be misinterpreted. In this chapter, I describe an ethnography of misunderstandings and of approaches I have taken to establish dialogues in a family with a non-verbal young man.[15] Instead of describing syndromes with which most people would agree, I

[15] This young man was twenty years old when I met him in 2008. In fact, he shows the ability to name

document how my understandings about the peculiarities of a young man evolve. For this young man, *misinterpretation*, here, means the one-way hypothesis offered by others for what he appears to be, rather than who he is.

My learning about this young man typically starts with misunderstandings. After a series of sessions in which I quietly watch the situation, I become a more active participant and try to contribute my solutions. I constantly adapt my perspective to seek resonances with both the mother and this young man. Instead of being an experimenter, a fieldworker documenting this journey turns out to be the most appropriate role. Agar (1980) describes fieldworkers as "professional strangers" who observe at a close distance. In this chapter, I present my observations in one form of fieldwork writing: the confessional tale (Van Maanen, 1988).

This chapter describes several important thought-processes in rhetoric and ethical concerns as I enter (and try being helpful to) an existing culture, a family. I choose to be a fieldworker instead of an experimenter. At the beginning, I was a foreigner who shared similar beliefs with the mother.[16] I find myself more comfortable arriving *without* the Externalization Toolkit described in Chapter 4. I do not come to this family with physiological tools and experimental plans in the first place. Still, my hope is to introduce technological tools that help the two-way communication.

Section 5.1 describes a series of visits taking place from winter 2008 to summer 2009. I take on the role of ethnographer before asking questions and suggesting new settings to try out. My visits also make me more comfortable in their house. In section 5.2, I turn into an experimental designer, apprehending possibility and searching for resonances. With his mother, I actively seek chances to develop a dialogue with the young man and to make a greater positive impact on their current situation. Later, I realize that seeking possible feedback is more pertinent (to me) than my original goal of creating a positive impact.

5.1 Witness

Each witness contains a transition from my misunderstanding to modeling interpretations.

Witness 01: The Greeting. I expect this young man to be defensive toward me, not allowing me to get too close to him, but I am wrong. He surprises me by asking me to scratch his arm, foot, and back on the day we met. I start as a stranger to this family. The mother of this young man guides me to understand the situation. Her role turns out to be more than an interpreter, explaining her familial environment. She often says to me "Don't worry," "It's okay," "no problem," when she perceives my surprises. She speaks French and has white hair. She is very articulate with stories about the family.

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objects and expresses his interests in his particular way. Because he does not speak or respond in the same way as typical people do, this young man may be labeled as non-verbal.

[16] In the following text, I will use "the mother" to refer the mother of this young man. She spent two hours interviewing me before permitting me to meet her son.

Obviously, she is more than a witness and an interpreter. She uses precise utterances to elaborate her thoughts and rationales clearly. She is the deeply experienced guide.

This special young man is a 20-year-old 6-foot-4-tall white male. When I see him for the first time, he is much taller than me. He seems like a giant.[17] The house seems crowded when he stands up. He is sitting on his own couch watching online video clips on his laptop with a headset. He peeks at me several times. I assume he enjoys watching the video because, most of the time, he appears very occupied and excited about what he is doing. He makes sounds, flaps his arms, rocks his body, and claps his hands. His sentences are sounds composed in English, French, and another language that I do not understand. He uses "Oui," that is, "Yes" in French, which is also one of the few French words with which I am familiar. He communicates with sounds that attract others' attention. I hear a few words related to foods, such as "Purée, orange juice, and carrots..." While I am busy receiving all the inputs from a new environment that is the home of two new friends, I am unsure about what to do next. This ordinary home is filled with unusual experiences. My brain does not allow me to move, but I tell myself, "Don't panic."

The mother quickly senses my discomfort. I am invited to sit on another sofa facing the giant and keep a five-foot distance away from him. The conversation between the mother and me is continuous. This first-hand information from the mother in this environment helps calm me down. When I am ready to approach him, the mother asks the giant to move his laptop onto my sofa and, in fact, to sit next to me. I am worried about what to do. But this unstructured moment does not last long. The giant says, "Tickle tickle." I am not confident in listening to English, especially when I do not have expectations of what kinds of words and sentences will be used. I think I might be hearing something wrong, but he repeats with gestures. He points to his arm and scratches it. Now I get it. He is asking me to help him scratch his arm. What a simple act of acceptance. I follow his instruction to scratch exactly where he wants me to do it for him, which includes his arm, feet, and back. This surprising interaction makes me more comfortable right away and brings me closer to him. This interaction is a valid friendly greeting between us, but I recognize it as reciprocal because we greet each other: first, in strange ways to both of us, and second, in our own particular ways.

Witness 02: Videos. The giant must love those animated videos that have cartoon characters with exaggerated expressions and sound effects. However, he seems to have his own way of watching videos. As I realize later, watching video for him might be like listening to a seminar and taking notes, while sometimes interacting with others who are also in the room. Watching YouTube videos is one of the major activities in his life as well as part of the vocabulary he can use to play and to pause in response to his surroundings. On several occasions he plays a specific clip to resonate with the situation. He may be constantly expressing himself, but others may not notice until more evidence reveals that his behavior is logical. The mother has given me many hints. Otherwise, I might have missed more.

[17] "The giant" is my first impression of this individual. I will use the term for the rest of the chapter.

When using his laptop, he seems no different from a guy who sits comfortably in the coffee shop watching videos. He uses a computer mouse. He clicks and double-clicks. After he reaches the web browser and the mother puts *Sesame Street* in the video search bar and presses enter, he becomes a pro in YouTube video indexing for finding clips he wants after a few clicks.

From the first page of search results, he seems to have a purposeful strategy for finding the videos he wants in a few clicks. The mother and I interpret the hyperlinks as his own path to reach clips he needs. The important ingredients are the side list showing a number of related videos—recommended videos. He does not type, but he asks for help to reach his *entry point* where he can find his own way of browsing and enjoying the videos. His favorite online videos include *Sesame Street*, and *Peter Pan*.[18] The one that arouses him the most at that point is the boat, where a fishing boat sails on the sea with crews catching large-size fish.

The giant appears not overly addicted to movies. He surprises me for his willingness to accept transitions. He can stop watching when his mother requests him to do other things. She also comments on how YouTube is a great tool to find movie clips they have lost. She used to have lots of videotapes of *Sesame Street*, and the giant used a VHS machine to play them. The giant also mastered locating specific scenes from a movie.

Witness 03: Tearing. Tearing paper is one of the giant's expressions when he seems over-aroused. When I first walked into the house, piles of torn papers were lying around the giant's seat. The giant often tears magazine pages into pieces.[19] These pieces have similar shapes, usually 1-inch (or less) in width with a regular page height. He tears multiple pages at the same time. He makes sounds while tearing. According to the mother, tearing is one of the routines when he watches videos on YouTube. One of many interpretations from the mother is that the sound of tearing seems to be a vehicle in responding to videos and his anxiety.

Witness 04: Rules. There are some strict rules applying to people and to things around the giant. Usually I have to break the rule first to find out there is a rule. For example, the giant is sensitive to others crossing legs when sitting on the sofa, but he always crosses his legs. He says firmly "No knees" to me when I sit on the sofa with my legs crossed. He is also sensitive to the order of things on the desk. If he sees they are not lined up well, he will go and adjust the position of the out-of-position pencil sharpener and calculator.

[18] The giant is currently exploring the same video clips in other different languages (e.g., Chinese, German…).
[19] The giant also tore this chapter once.

Witness 05: Routines. Human attention is limited. It is easy to miss critical information in everyday routines. Things can happen unexpectedly if the important message from the giant gets ignored. Keeping full attention at all times is exhausting. However, the mother must accompany this individual full-time and usually with full attention. Every week, she writes down their schedule on a whiteboard. Within the schedule, the giant has several 1~2 hour time slots to interact with his special education teacher, musician, painter...who make up a community around this family. During this time, the mother is able to offload herself. She also states that "one of the most important functions the school provides is the half-day separation." I certainly agree with her. It seems to me staying alert and calm is needed when interacting with the giant in order to stay alert for any valuable but fragmented information. I hope to present some technological solutions to this situation in order to reduce these mental demands for her and people that might be in the same situation.

5.2 Interventions

Each intervention is an attempt to debug my misinterpretation.

Intervention 01: Painting on Videos. I think the giant likes painting. Instead, he seems to enjoy the process of painting more. He paints using old toothbrushes instead of regular paintbrushes. He likes to mix colors and stir them into a uniform color, and he then uses toothbrushes to paint on the canvas. The mother schedules weekly painting classes with three artists. He also paints with other friends that visit them on a regular basis and, of course, he paints with his mother. I see several times that the giant is painting over his previous paintings that were painted with uniform colors.

The Giant had tried this with his younger brother and his mother several times before. For example, placing a transparency painted with colors on the laptop screen combines two of his favorite activities. We, the mother and I, attempt some variations of video-related installations. First, I bring a video projector to their place and project the movies he watches on the wall. In such a setting, his videos become public and he seems to enjoying watching movies on a *large* screen a lot. Perhaps, it gives him more visual stimulation. Second, we set up a canvas on which we project the video, so that he is able to paint while we play different movies simultaneously. The overlaying of painting and watching movies may sound overwhelming, but in fact, the Giant seems to enjoy this stimulus environment. He makes sounds like he does when he watches YouTube videos. He also gives directions about what videos to play next, as well as brushing with the different colors he requests. One thing he does not like is to get his hands dirty with paint. He needs to have his hands cleaned so that he can go on.

The Giant exhibits his ability to resonate situations with his clips. On one occasion, the combination of painting and the movie make it looks like curtains with rainbow colors. We do not notice anything until the Giant guides us through a series of hyperlinks and then finds the movie that resembles the scene. Another example is that he asks for a movie clip that has a short sequence with flowers and the sun. A couple of minutes later, the mother tells me that movie scene resembles the shapes he painted on the canvas. The processes of reaching a conversation are not hard. However, they do require a great sense of observation, memory, and patience. These efforts pay off when a connection emerges.

Intervention 02: The Video Performance. It is a birthday present for the Giant's 20th birthday. A video performance with two large projection screens is held. I see his smiling face when he discovers the screens playing *Sesame Street* movies. He sits on a comfortable sofa like the one he has at home. I can tell he seems very excited. He is flapping, rocking, making sounds, and tearing papers. His excitement is like a message to me, telling me he likes it a lot. I still remember my own panic when I first saw him flapping and making sounds. Now, the familiarity has empowered my ability to perceive his messages. The mother is sitting next to him. I stand behind his sofa. About 20 friends and relatives (his grandparents came all the way from France to celebrate his 20th birthday) attend and sit around him, as shown in Figure 6-1. Two video projectors are arranged at an angle where the Giant controls one screen. There is no speaker. The Giant wears a wireless headset for audio. This space remains silent. I also prepare paper and magazines for everyone to tear.

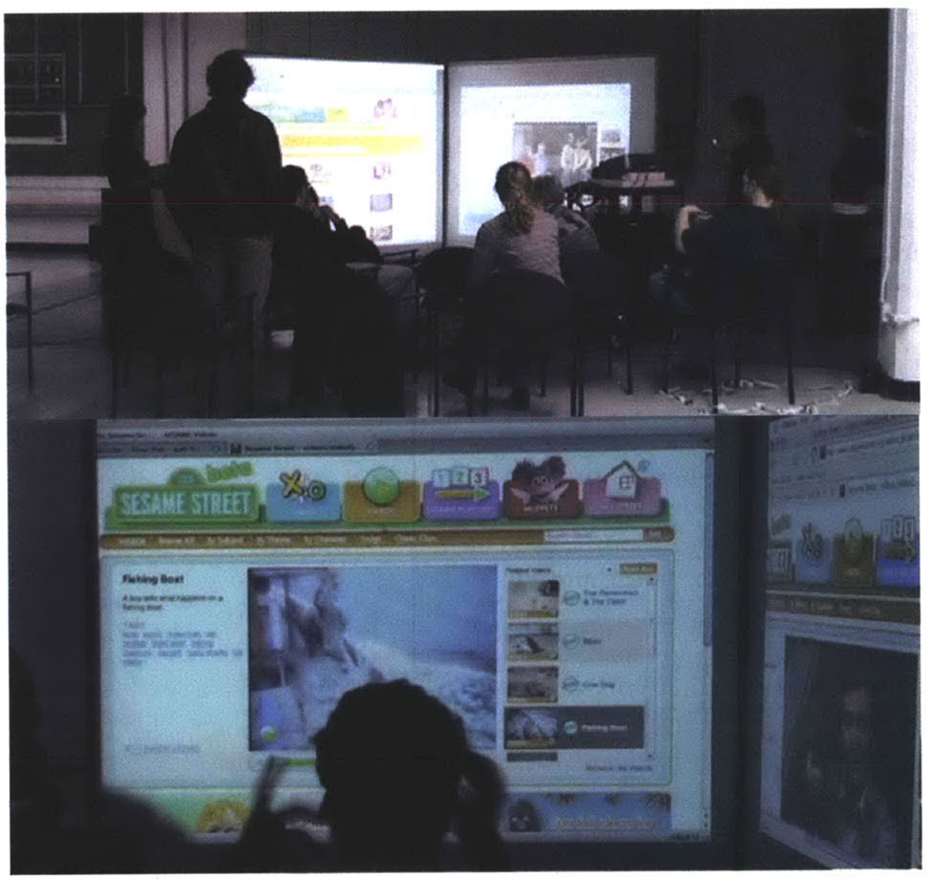

Figure 5-1. The Video Performance by the Giant.

Intervention 03: Tearing. Can tearing become a means to communicate with him? My first attempt is to tear pages with him. I sit on the floor next to his seat. I try: first, I tear right after he tears, I tear at the same time with him, or I tear without thinking too much. The difference could be too subtle to discover. Then, I decide to be more aggressive. How about if I tear his half-torn paper in his hand? He says firmly, "NO." I did not give up. "There must be something worth discovering in tearing," I say to myself.

Finally, I tear the paper half way and present this half-done job to him waiting for his response. He holds and tears the rest of the page while I am holding the other side of the page. He turns his face to me. He looks at me and then calls my name "Jackie." This is another important moment for me. It seems that the Giant and I are sharing the same goal—tearing paper— after a series of trial-and-error misunderstandings. This is a great advance since we greeted.[20]

Another attempt is made with the tearing when I bring the video clips of the Giant tearing papers to a group of students in the Autism Studio class.[21] I also prepare magazines next to those students' seats. I play the video on the projection screen. As soon as the movie begins, I observe how others respond to his tearing. The Giant keeps tearing on the big projection screen. Some students find the magazines available next to them. They start tearing, too. With a camcorder on my hand, I record this "watch-tearing-then-start-tearing" resonance. I believe this clip can be good material to which the Giant can respond. I am excited, and present this to him. It does not work in the ways as I expect, but he does respond to other parts of the movie—parts where he is tearing.

Intervention 04: Gearing up the Externalization Toolkit. The inter-relationships between the Giant's favorite movie clips are mysteries, and the mother and I are both curious about them. I bring the Externalization Toolkit (developed in Chapter 3) to the family and propose to record the Giant's physiological signal (i.e., skin conductance) while he is watching videos. This is not because of the technology, but because the use of technology immediately transforms the relationship between the Giant and me into a relationship of a subject and an experimenter. The data could have been selfishly collected without my understanding who the Giant is. As an experimenter, I could have asked to have the Giant do something he did not want to do. I could have abused the technology. On the basis of the confidence, the trust, and the many other positive emotions built with the family, I feel permitted to bring in my toolkits.

First, I explain how a physiological sensor works and how I will collect data.[22] The mother quickly raises questions such as "What does it mean when we see a peak or when the readings go up?" "Is it consistent?" "What else could this device teach us?" These are great questions to a psycho-physiological researcher, because I am seeking good

[20] This greeting refers to the way the giant and I greeted when I helped him to scratch his arm.
[21] Autism Studio was a class led by Wendy Jacob at the MIT Visual Arts Program in Fall 2008.
[22] A customized software interface was implemented to receive data from iCalm wireless skin conductance sensors and to mark events (via pressing keys).

answers too. Later, we finalize a time to do the physiological recording while the Giant is watching YouTube movies.

The Giant does not tolerate wearing the iCalm wristband. He takes it off almost immediately. The mother asks if the sensors would work on another location of the body and tries putting the wristband on other parts of his body. She flips the wristband and makes the Ag-Ag/Cl electrodes face outward, so that she can put this inverted wristband inside the Giant's shirt. She tries his back, his foot, and his belly. He does not tolerate any of these placements on that day. It is because, the mother assumes, the Internet connection is slow, and he is not able to devote his full attention to the movies. Instead, his attention is on the sensors on his body. However, during the second meeting, the Internet problem is resolved. The Giant is able to tolerate the band on his belly. I check the SC reading, and it picks up recognizable responses of tonic and phasic changes. I set up the YouTube video via video projection. The recording is ready.

Figure 5-2. The non-verbal individual was watching YouTube movies while his mother was predicting his physiological arousing event via Physioboard.

An ad-hoc study of predicting the Giant's arousing moments has begun. In a 30-minute session, the Giant watches his favorite movies via YouTube and while wearing iCalm SC sensors. I ask the mother to notify me of his arousing moments, such as by saying, "Now he is getting excited," based on her experience. She cannot see the software interface. I press keys to mark arousing events. A successful interpretation occurs when an event is marked just before level or phasic changes in skin conductance data. As shown in Figure 6-2, the vertical red lines indicate the mother is able to predict some arousing events. SCLs of this individual were responsive and corresponded to his overt behaviors (e.g., he flaps his hands when excited) when watching the videos. Some calming events were also identified when the Giant smiled and focused and his SCL decreased. In this setting, it seemed impossible for the mother to do the recording herself.

Figure 5-3. Two video-watching sessions are recorded with three of us wearing the iCalm sensors.

Analysis of aggregated skin conductance data. Two other video-watching sessions are recorded with three of us wearing the skin conductance sensors, as shown in Figure 6-3. I aggregated our data and plotted the two sessions. During the first session, coded as CV-01, the red line is the Giant's skin conductance data, the purple line is the mother's, and the blue line is mine, as shown in Figure 6-4. After the data collection program (Physioboard) starts, I test the three wristbands to see if they are all functioning correctly before I put them on the Giant and the mother's wrists. In CV-01, at the beginning, there are conversations between the mother and me in discussing the video, the setup, the sensors, and the Giant. For the first 10 minutes, the data shows visually similar pattern of concordance. My interpretation is that the conversation made us both attentive and interactive in a similar sensory stimulating way so that both the mother and I show active responses of SC activity.[23] After that, the mother and I focus on the Giant and his video. However, I am alerted at all time with active SC activities. There are fewer activities in the mother's SC data after 10 minutes. My guess is that the mother might find this "experiment" boring. It might also be because the Giant does not respond actively. About 5 minutes after the video starts, the Giant shows he is very engaged in the videos. He flaps his hands when his favorite scenes show on the screen. The SC elevation from the 7th minute to the 20th minute corresponds to the Giant's excitement. Inspecting this session from the Interactive Physioboard shows the Giant's hands are mostly in the air and flapping during that arousing period. After the 20th minute, his hand is holding the mouse without doing much flapping. At the end of the session, I double-checked if their sensors were functioning by touching the electrodes on the wristband that the mother

[23] This interpretation is made for an exploratory explanation of using the physiological data. Its validation can be questioned and requires more rigorous investigation.

was wearing. As shown in Figure 6-4 (Top), at the 50th minute, the purple line overlaps with the blue line when I put the electrodes on my hand.

In CV-02, this plot shows that the blue line, my SC data, is responsive throughout the session. But the Giant and the mother's SC data are not as responsive as mine. At the 10th minute, the Giant took off the sensors. At the 11th minute, a concordance response occurs (i.e., all of our SC data show peaks) when we try putting the sensors back on the Giant's body.

To record all the participants' SC data and to analyze their interaction and concordance seems very interesting, but this could be done in a very controlled environment for careful inspection. To take this approach further, more detailed information needs to be captured, such as the content of the videos.

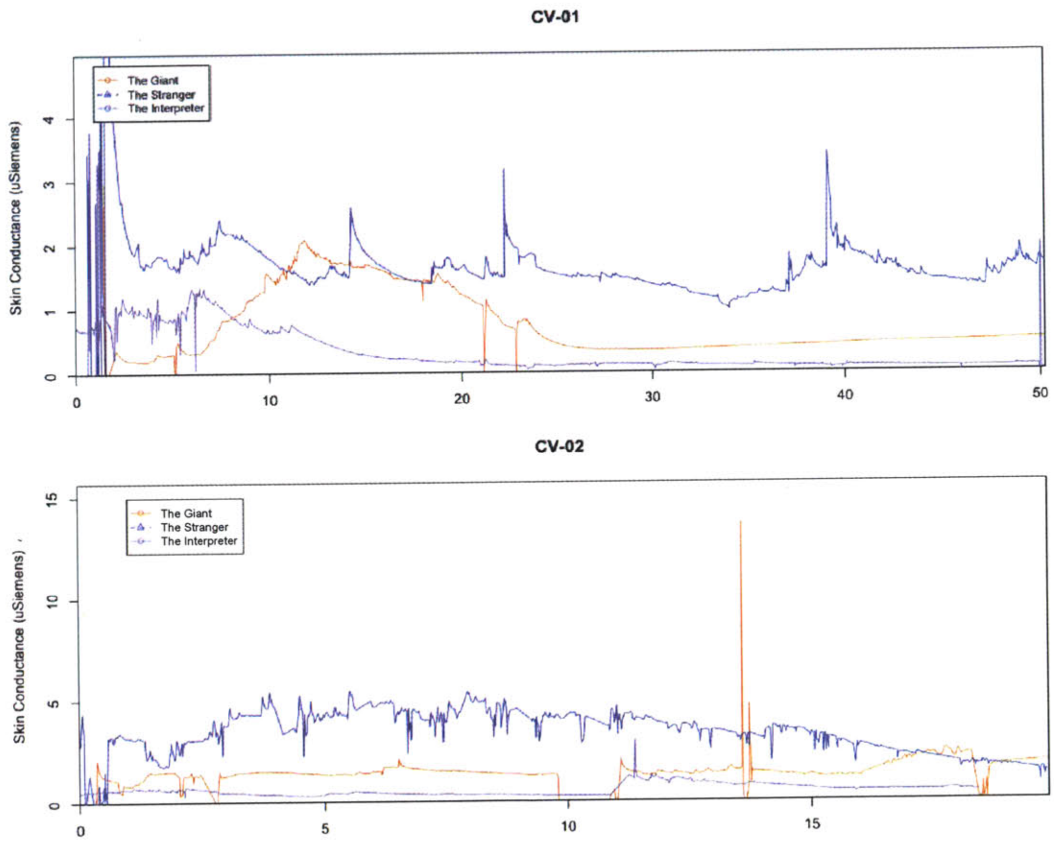

Figure 5-4. These two plots show two recordings of physiological concordance of the Giant, the Interpreter (the Mother), and the Stranger (me). The three persons wore the iCalm wristbands and watched the Giant browsing YouTube movies on a projected screen.

5.3 Summary

This chapter presents an ethnography of my understandings with a young man—the Giant—and his family. I document the discoveries of how I debug my misunderstandings on an *interpersonal* scale. First, when I initially meet his family, I arrive with assumptions and biases that I am not aware of. Many interpretations are made based on my default knowledge about typical people, *DSM* descriptions of mental disorder, and how this young man appears. Before closer and more frequent interaction, I realize I have made a biased hypothesis that leads to misinterpretations of what I saw based on his unusual behaviors and the sounds he makes. Using terms such as "sensory disturbances" about him or the unusual sensory capabilities he has is over-simplifying the context and the situation because there are hidden reasons and clues leading to why he responds in his own vocabulary. Before establishing any *dialogue* with him, these clues remain symptoms that are less tolerated in a typical social life.

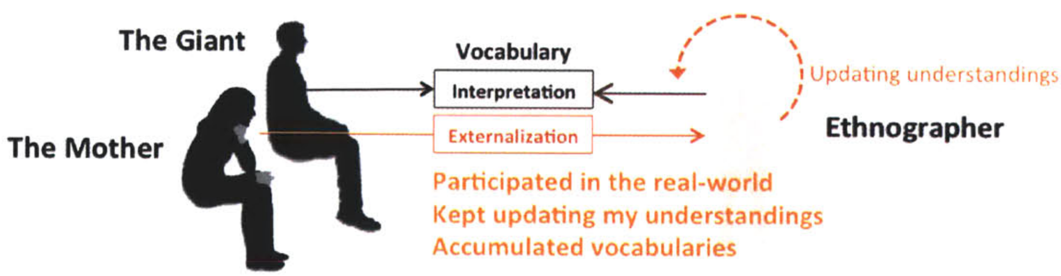

Figure 5-5. The interaction diagram of the home-based study.

As I choose to be a stranger instead of an experimenter, I must ask, "What should I do?" As his mother supplies more information and more interaction occurs, I discover more clues that might eventually become the basis for a "conversation." Figure 5-5 is a diagram that summarizes the interaction among three of us in this study. The mother has been externalizing the Giant's inner states for me, so that I am able to update my understandings and to make more precise interpretations.

To form a conversation of a non-verbal nature seems difficult, especially when the vocabulary is not set. I seek to join some possible on-going conversations (i.e., tearing paper, watching Sesame Street videos). The Giant's participation, attention, and his responses are crucial to my participation because these clues will direct me to the *context* that has complex inter-connections with his perceptions, but is fragile. The context can be easily shattered and disappear from my attention. However, his mother—the interpreter— is playing an important role in keeping my focus on clues that she is aware of. Relating the video-watching with the paper-tearing event may sound irrelevant to people who are outside of this context, but these two activities become platforms that allow their derivatives to grow and to continue the conversation.

The Giant's responses are both strong and subtle. His determination is strong with firmly fixed eyes, but the reason why he responds is subtle, sometime invisible.

When interacting with him (i.e., sitting next to him, watching videos with him, and having conversations with his mother), it often requires fluent responses: changing strategy, making variations of interaction, and resonating with his attention. I would not have fluent responses if I were not creating attempts to approach a shared vocabulary. Reaching moments of "sharing the same goal" with the Giant after a series of discoveries has been the most valuable experience, because shared understandings are established and they become the foundation for further understandings.

Chapter 6

The Lab-based Study

An experimental-driven approach

Helping them to cope with stress requires reducing demands, increasing supports, and giving them more control over themselves and their environments.

June Groden, 2007

This dissertation presents a lab-based study aiming for studying a caregiver's interpretation of his/her teenage student's autonomic arousal states in a controlled environment. In this study, I investigate in a laboratory setting how a class teacher estimates his/her student's arousal states in the twice-daily routine of progressive muscle relaxation at the Groden Center. At a special educational institution, caregivers, such as the class teachers, interact with the students on daily basis. Class teachers have to pay attention to several students at one time, understand what might cause discomfort to their students, and make quick decisions about students' over-aroused situations. Class teachers might be mentally overloaded while simultaneously paying attention to the students, the school environment, and possible disruptions that some students cannot tolerate. I hope to ease the teachers' situation by introducing a direct channel showing their students' arousal states. To accomplish this, this study investigates how well the teachers are assisted by two kinds of physiology-based displays developed in this dissertation (the MiniHeart and Physioboard). To measure students' arousal states, we deployed two existing research prototypes: the iCalm skin conductance sensor (Fletcher et al., 2010) and the ear-mounted heart rate sensor (Poh et al., 2010).

6.1 Motivation

Can stress be tracked in people diagnosed with autism? Stresses might not be observable from a person's overt behaviors before an extreme emotional state such as a meltdown or tantrum. People diagnosed with autism are usually equipped with different ways of perceiving and reacting to stressors that could trigger meltdowns or other misbehaviors (Baron et al., 2006). Some antecedent situations can be identified in order to minimize the impact, but some meltdowns can happen seemingly out of nowhere. On the basis of current neurology and physiology, researchers are able to characterize and measure stresses by monitoring physiological arousal in the autonomic nervous system (Matsumoto et al., 1990). Skin conductance (SC), heart rate (HR), and heart rate variability (HRV) are understood as indicators closely related to stress and anxiety (Hirstein et al., 2001; Levy, 1984). Heart rate has been used as a typical physiological indicator of stress and arousal and has been shown to have atypical ranges in a group of school-age children diagnosed with autism (Goodwin et al., 2006). I am part of a group of researchers in the MIT Media Lab that has developed wireless physiological sensors capable of comfortably recording physiological data and displaying real-time data in various ways. We would like to understand how stresses could be *monitored* based on these tools. In this study, we would like to find a strategy of interpreting stress-related physiological data in people diagnosed with autism.

Can physiological technologies be incorporated into daily routines such as the progressive muscle relaxation (PMR) training at the Groden Center? We learned that progressive muscle relaxation (usually called "relaxation training"), developed by Dr. June Groden (Cautela & Groden, 1978; Groden et al., 1994), is routinely used twice a day as a technique to decrease and to manage stress and arousal. However, it is often difficult for teachers and caregivers to determine internal arousal states objectively in children with autism and thus know if they are achieving the physiological benefits of relaxation. The goal of this study was to assess how various real-time displays of student physiological activity affected teacher estimation of arousal and relaxation. This experiment was not designed to study the efficacy of PMR, but was a context for assessing the impact of various physiological displays for teachers to estimate their students' fluctuating internal arousal states.

In real-world situations, class teachers usually depend on their experience to interpret their students' behaviors and to estimate their inner states in order to answer very common and frequently asked questions: "How aroused is s/he? What should I do for him/her?" Behavioral interpretation based on what is present overtly is usually the only way a typical teacher relies on in the classroom. Via wireless and wearable sensors, collecting autonomic arousal data makes real-time arousal externalization possible. However, when the real-time physiological arousal data are in front of the teacher, how does the teacher use it in practice? To investigate this question, I built Physioboard as a screen display showing HR beat-per-minute (BPM) and trend, and the MiniHeart, which pulses and vibrates in sync with heartbeats. This experiment seeks to establish a strategy to help communicate inner states of our autistic teenage participants.

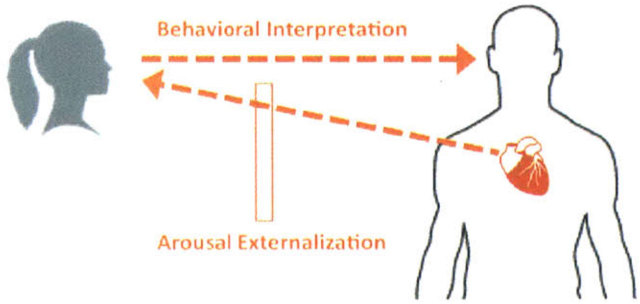

Figure 6-1. The Relaxation Experiment consists of two parts: externalizing arousal via physiological tools and how others interpreting behaviors.

Two major parts of this experiment, as shown in Figure 6-1, include arousal externalization and behavioral interpretation.

6.1.1 Arousal Externalization. Physiological measurement usually takes place in a laboratory setting monitored by experts. What if class teachers are able to collect physiological data and use them as references for estimating their students' inner states? At the MIT Media Lab, Affective Computing Group created wireless wearable physiological sensors for measuring autonomic arousal activities from skin conductance activities and heart rate (Fletcher et al., 2010; Poh et al., 2010). We assessed HR using a wireless ear-mount sensor and SC using a wristband in a group of teenagers diagnosed with autism while they participated in this study in order to understand how to discover or how it could provide new insights into an individual's arousal characteristics.

6.1.2 Behavioral Interpretation. Can tools also help caregivers (e.g., classroom teachers) to interpret individuals' internal states? It is often difficult for caregivers to determine a child's internal arousal state objectively. Since "relaxation training" is a procedure to let students feel and get control over their muscles as well as inner states, we would like to deploy our physiological tools in order to study how these tools could help teachers estimate how aroused students are.[24] I extend physiological sensors by making hardware and software that display physiological data via intuitive ways. For example, the MiniHeart (Section 4.1) is a LED-vibro-tactile device that pulses in synch with real-time HR for perceiving HR change in a tactile way, and Physioboard (Section 4.2) is a heart rate monitoring interface in order to track HR visually. In this study, I experimentally manipulated teacher access to physiological data (no real-time physiological data, Physioboard, and MiniHeart) to see how visualizing HR affects teachers' appraisal of student arousal during the procedure.

[24] We really like to let the student get this feedback as well, but that was not part of the study, as this was intended more to assess the tools and information they provide within the current routine than to introduce a new biofeedback practice.

6.2 Methods

6.2.1 Participants. We recruited student participants diagnosed with autism and their class teachers from the Groden Center, RI. Before the formal experiment, investigators conducted pilot studies and four workshops with mockup sensors and demonstrations (without data recording) in order to have our participants get familiar with the experimental room and devices involved in this study. We expected that all participants, students, and teachers felt comfortable wearing and being familiar with using our devices prior to the formal experiment.[25]

Student participants. Seven student participants (age 7-17, 5 male and 2 female) diagnosed with autism via the Autism Diagnostic Observation Schedule, ADOS,[26] enrolled in this MIT IRB-approved study at the Groden Center, as shown in Table 6-1. Each student participant was accompanied with his/her own class teacher who interacted with the student on daily basis. Student participants were asked to wear wireless physiological sensors during the study. Their heart rate and skin conductance data were also collected. Student participants were blinded for the physiological displays.

Table 6-1. Participant Characteristics

Participant (with coded ID)	Age	Sex	Diagnosis
P01	7	Male	Autism (ADOS)
P02	17	Male	Autism (ADOS)
P03	10	Male	Autism (ADOS)
P04	10	Male	Autism (ADOS)
P05	8	Female	Autism (ADOS)
P06	14	Female	Autism (ADOS)
P07	10	Male	Autism (ADOS)

Teacher participants. Teacher participants led their own students, received different kinds of physiological display conditions, and rated their estimations of students' arousal states during the study. Class teachers were able to understand and respond to students' situations and special needs. In a classroom, there are usually three to four teachers taking care of four to six students. Their tasks involve teaching and training students for their basic living and communication skills as well as exploring their styles of interaction and personalities. Class teachers are able to react quickly to students' emotional status, ranging from getting impatient to appearing uneasy to any emergent situations. Each teacher had from three months to many years of experience interacting with student participants before the study.

[25] Four small workshops (2~3 teachers with their students) were held before the formal study. All student and teacher participants had tried the sensors and devices prior to the formal experiment.
[26] de Bildt et al. (2004) reported that the Autism Diagnostic Observation Schedule (ADOS) is a diagnostic measurement for autism equivalent to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV).

At the Groden Center, class teachers work with researchers, occupational therapists, and psychologists so that teachers can provide the most appropriate support to students with special needs. Compared to experimenters who may cause stress to students while conducting the experiment, class teachers may cause less stress to them. In order to preserve the settings of the regular routine into an experimental setting, class teachers were more appropriate than investigators who might possibly become stressors to these students. Each class teacher worked with investigators in order to be familiar with the experimental setup and procedures so that they were able to lead the experiment without the investigators present in order to minimize impact from unfamiliar persons.

6.2.2 Experimental Design. This study involved a single-case design of baseline phases, progressive muscle relaxation phases, and rest phases. Single-case experimental design is helpful for understanding how operant conditioning interacts with the participant over a period of time with frequent repeated measurement of the interaction (Kazdin, 1982). This study sought to extend further the measurement protocol from Groden et al. (2005) and Goodwin et al. (2006). Instead of studying daily stressful situations in previous studies, this experiment tested one of the daily routines, the progressive muscle relaxation.

Potential environmental and experimental stressors may cause participants to be aroused. Goodwin et al. (2006) illustrated potential arousal induced by the testing environment. Goodwin (2006) suggested alternative experimental settings:

1. Participants can be allowed to get familiar with the equipment, the experimental room, and laboratory settings prior to the formal study.

2. Experimental equipment needs to provide maximum comfort to the participant. For example, a wireless HR measurement tool eliminates wired connections to the participant's body.

3. The experimental room can be set up in a minimally stimulating manner, such as incandescent lighting, pattern-free walls and carpet, and soundproofing.

4. The participant can be accompanied by a familiar person during the study.

This study followed these suggestions for arranging the experimental environment in the following ways:

1. Participants (both teacher and student) were able to sit inside the experimental room and to try out the procedure and the devices (without recording function) before the study.[27]

[27] Most participants were familiar with this experimental room. Some participants repeatedly attended studies in this room.

2. We presented a wireless ear-mounted heart rate sensor so that there was not any wire connected to the participant.[28]

3. The experimental room was set up with incandescent light, pattern-free walls, and carpet.

4. A familiar person (his/her class teacher) was leading the experiment.

Students diagnosed with autism wore wireless HR and SC sensors for the duration of each session. The student's class teacher led each session. Pilot sessions were conducted with all participants to familiarize them with the experimental design, as well as minimize stress associated with a novel task. Two physiology-based interfaces were introduced to assist teachers in estimating their students' autonomic arousal during relaxation training. Four training sessions were provided to teachers to familiarize them with the interfaces.

Procedures. In a quiet room of the Groden Center (in the building where the participants attended the school), a familiar teacher led students through the following seven phases and setup: 0. preparation (e.g., helped put ear-mounted sensors on student and began recording), 1. baseline (2min), 2. guided relaxation with intervention 1 (2min), 3. rest (1min), 4. guided relaxation with intervention 2 (2min), 5. rest (1min), 6. guided relaxation with intervention 3 (2min), 7. baseline (2min).

Table 6-2. A single case experimental design with technological intervention

Phase 0	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**
Before the study	**Baseline**	**Verbal-Guided Relaxation** (intervention 1.)	**Rest 1**	**Verbal-Guided Relaxation** (intervention 2.)	**Rest 2**	**Verbal-Guided Relaxation** (intervention 3.)	**Baseline**
15~0 min	2min	2min	1min	2min	1min	2min	2min

In the three guided relaxation phases, the teacher experienced three intervention conditions, in randomized order: 1) no real-time data display, 2) screen-based display showing the student's real-time HR in beats-per-min (BPM): Physioboard, 3) the MiniHeart, a physical tactile device that blinked and vibrated according to the student's real-time BPM. Teachers also rated how behaviorally aroused the student appeared (1: very relaxed to 5: very aroused) after each experimental phase and were interviewed after the study. As shown in Table 6-2, the experimental procedure consisted of seven phases and preparation (phase 0.):

[28] The ear-mounted sensor was made based on the shape of an adult's ear. It took extra work to install the sensors on some younger participants' ears (e.g., P01 and P05).

Phase 0. Preparation (15min before the study to 0min). Pre-experiment setup included:

1. The investigator set up the environment. At fifteen minutes prior to the scheduled study, the investigator visited the student participant in his/her class. The investigator asked the class teacher to ensure the student had no problem proceeding with the formal study. The investigator put on the skin conductance wristband on the right wrist of the student participant.[29] The electrodes of the wrist sensor were placed on the inner wrist.

2. At the scheduled time, the teacher led the student participant to the experimental room. The teacher asked the student to sit comfortably on the chair. The investigator greeted the teacher and the student participant. The teacher put the ear-mounted sensors on the student participant. The investigator would help if the teacher had difficulty in putting the sensors on correctly.

3. The investigator handed the instructions and questionnaire to the class teacher. The investigator uncovered the screen and checked Physioboard to see if the computer was receiving the sensor signals correctly. The teacher asked the student if s/he felt comfortable wearing the sensors. If the student felt uncomfortable, the teacher would inform the investigator and interrupt the study immediately. The investigator ensured the study was ready. Class teacher started the conversation with small talk (e.g., "What did you have for breakfast? Where did you go during the vacation?"). After a short chat to make the student feel easy, the teacher asked the student to sit quietly.

Phase 1-Baseline (0~2min). Baseline started when the teacher asked the student to sit quietly, close his/her eyes, and relax for two minutes. The teacher received the investigator's signal to end this phase. The teacher participant rated how aroused the student appeared on the questionnaire and then proceeded to the next phase.

Phase 2-Verbally guided relaxation (~2min[30]). Guided relaxation phases with randomized interventions started when the teacher received the investigator's signal to lead the progressive muscle relaxation training. After that, the teacher rated how aroused the student appeared on the questionnaire.

Phase 3-Rest (1min). Rest 1 started when the teacher asked the student to sit quietly for one minute. The teacher received the experimenter's signal when one minute was up. The teacher rated how aroused the student appears and then proceeded to the next phase.

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[29] The investigator made sure the wristband was clean and used alcohol wipes to clean the contact electrodes.

[30] Guided relaxation was designed to be within two minutes. However, depending on the teacher's leading style, it ranged from 1 to 2.5 minutes.

Phase 4-Verbally guided relaxation (~2min). Guided relaxation started when the teacher uncovered the computer screen (if screen display intervention were chosen) and initiated the guided relaxation. The teacher led the relaxation training (the same steps). At the end, the teacher asked the student to sit quietly for a minute. The teacher rated how aroused the student appeared.

Phase 5-Rest (1min). Phase 5 started when the teacher asked the student to sit quietly for one minute. The teacher rated how aroused the student appeared after receiving the experimenter's signal when one minute ended.

Phase 6-Verbally guided relaxation (~2min). Guided relaxation started when the teacher used the MiniHeart (if LED vibro-tactile intervention were selected) and initiated the guided relaxation. At the end, the teacher asked the student to sit quietly for a minute. The teacher rated how aroused the student appeared.

Phase 7-Baseline (2min). Baseline started when the teacher asked the student to sit quietly for two minutes. The experimenter tapped the glass when two minutes was up, and the experiment ended.[31] The teacher rated how aroused the student appeared. The teacher (or the investigator) took off the sensors from the student and led the student back to his/her classroom. The study ended. The experimenter interviewed the teacher afterward.

6.2.3 Instrumentation.

Progressive Muscle Relaxation. The progressive muscle relaxation (PMR) program is a teacher-guided activity for students to tense and to relax their muscle groups in a progressive way (Cautela & Groden, 1978; Jacobson, 1938). PMR aims to help individuals decrease and manage stress and arousal. PMR (usually called "relaxation training" at the Groden Center) is routinely performed twice a day. The original design of PMR was a twenty-minute full-muscle tensing and relaxing activity guided by trained instructors. At the Groden Center, the relaxation training was modified into a shorter 3~5min version in order to accommodate its real-world usage.

When designing an experiment involving three relaxation trainings, we learned that the whole experiment should be less than ten minutes long because most students might get uneasy; also, we could record a decent quality of physiological data in a short interval, repeated twice a day over many sessions. After discussion with research staff and class teachers, we altered the 3~5min relaxation training into a 2min version in order to keep the students attended and patient.[32] Before the formal experiment, we arranged for

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[31] We double-checked for signs of startle caused by tapping and found none in the data.

[32] Investigators decided to take the tensing part out of the experimental version of the relaxation training PMR. In this case, teachers only need to instruct students doing the relaxing part instead of doing both tensing and relaxing, so that the whole experiment with three verbally guided relaxations would be reduced from 20 minutes to 10 minutes. Since most students were used to the 3~5min guided tensing-relaxing relaxation training, this modification could influence participants. This issue

teachers and students to sit in the experimental room and do the experimental version of the relaxation training. In this study, class teachers led the PMR training and instructed softly in the order shown in Figure 6-2. This is the normal procedure for the relaxation part of their standard routine. Teacher mentally reads "one-one thousand, two-one thousand, three-one thousand" before prompting the next step. This pace will keep this relaxation phase around two minutes.[33]

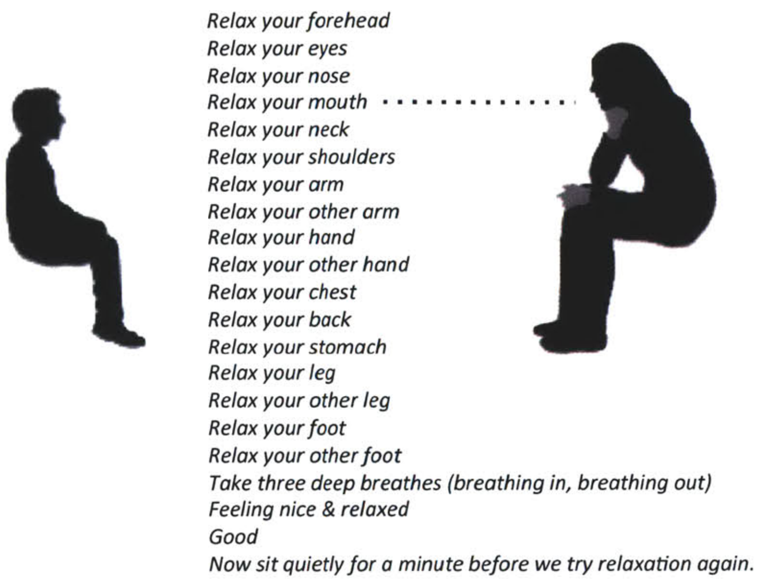

Figure 6-2. The modified version of the verbally guided relaxation

Skin conductance wristband sensor. This study utilized an existing hardware platform, iCalm skin conductance sensors (Fletcher et al., 2010), with customized software. The iCalm skin conductance sensors are small, wireless, and low-cost physiological sensors developed by the Affective Computing Group, MIT Media Laboratory. Figure 6-3's diagram illustrates the mechanics of the iCalm skin conductance sensing. In this study, an iCalm sensor measures electrodermal activity (EDA) from two Ag-Ag Cl dry electrodes across the surface of human skin on the right inner wrist. iCalm sensors measure electrical conductance that reflects the amount of sweat in the glands under the skin. The amount of standing sweat in the glands increases when the sweat gland is stimulated by the sympathetic nervous system (Dawson et al., 1990).

The iCalm sensor board processes measurements of EDA into skin conductance levels (uSiemens) to capture tonic and phasic responses representing autonomic arousal. The skin conductance wristband measures autonomic arousal during progressive muscle relaxation training and wirelessly transmits the values to a laptop (10 bit 2Hz ADC). Skin conductance (SC) electrodes are usually placed on the fingers or palm. Skin

needs to be further investigated in future work.

[33] According to participants' class teachers, being asked to sit for about ten minutes can be disruptive to some of the participants.

conductance measured from the inner wrist is as responsive as from the palm (Poh et al., 2010). However, the best location may differ from person to person because of comfort, motion artifacts, and skin responsiveness to sensors. Poh (2009) found Ag-Ag CL dry electrodes provide the most responsive electrical signals when compared to fabric electrodes. In this study, we placed skin conductance (SC) sensors embedded inside a sport wristband on the participant' right inner wrist at fifteen minutes before the experiment.

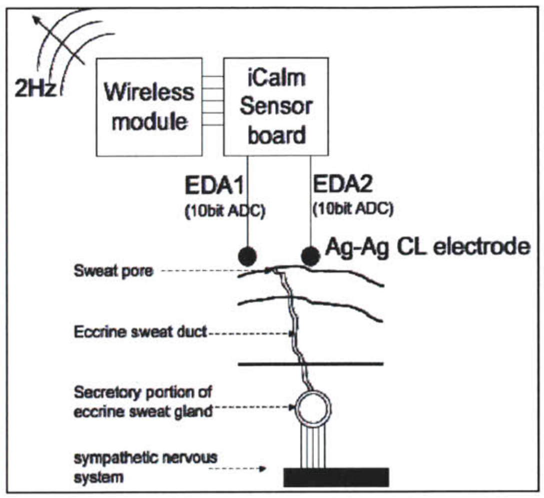

Figure 6-3. iCalm sensors measure EDA that reflects sympathetic nervous system activation.

Ear-mounted heart rate sensors. This study utilized an existing ear-mounted heart rate (HR) sensor (Poh et al., 2010) for heart rate measurement, as shown in Figure 6-4. Average HR usually goes up with increasing physiological arousal. This ear-mounted device measures heart pulsing based on a photoplethysmogram (Allen, 2007) waveform. This HR measuring device samples and wirelessly transmits the PPG waveform at 12bit 20Hz. This device detects blood volume intensity, which reflects beat-to-beat heart rate. The sensors are attached with magnets placed on the right earlobe like a sandwich (i.e., magnet-earlobe-magnet). The receiver connects to a computer via USB/serial port. In this study, this device required the investigator to help participants to place the sensors correctly. A customized software driver was implemented and installed on a laptop for retrieving and processing PPG waveform data into real-time heart rate readings.

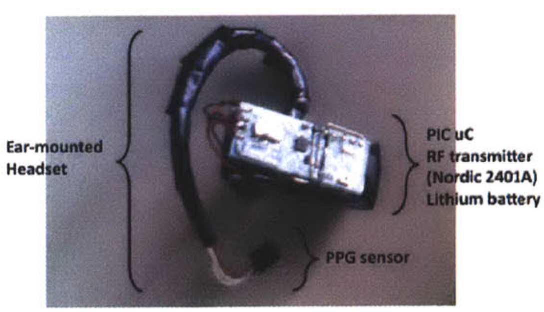

Figure 6-4. (Left) Ear-mounted heart rate sensor as an HR transmitter (Poh et al., 2010). (Right)

MiniHeart as an HR receiver.

MiniHeart. A hand-held heart rate indicator is deployed for providing visual and tactile perception of autonomic arousal (heart rate). The MiniHeart provides an alternative way of representing heart rate other than reading numbers of the averaged heart rates. The MiniHeart is able to display heartbeats via a pulsing LED with vibrating tactile actuation. The intensity of the pulsing LED and tactile actuation maps to the bodily rhythm-heartbeats provided an illusion of an external heart. The MiniHeart wirelessly received the heart rate data from the heart rate earring sensors (Poh, 2010). The blinking LED enhances people's attentiveness to the device. If the MiniHeart were put inside a pocket, it would become a personal heart rate indicator via its tactile vibration. In this experiment, the hand-held indicator was placed inside a black bag so as not to distract the student participant. The teachers were able to open the bag and touch the device quietly when they were leading the experiment. The MiniHeart was hidden from the student participants throughout the study. Only the teacher was able to watch the pulsing light or feel its vibration in order to access the heartbeat information from the student.

Physioboard. A screen display intervention is deployed for assisting teacher participants in estimating how aroused their students appeared as one of the technological intervention for the teacher participants only. Student participants were blinded to this intervention. Physioboard plotted heart rate (HR) beat per minute (BPM) on screen so that teachers were able to trace the HR trend visually. Student's averaged heart rate BPM was updated in real-time for a 30-second moving window. This software captured the overt behaviors (from the camera) with inner arousal (HR) on one screen that allowed the teacher participants to keep their attention on the student in the camera view when they looked at the screen.

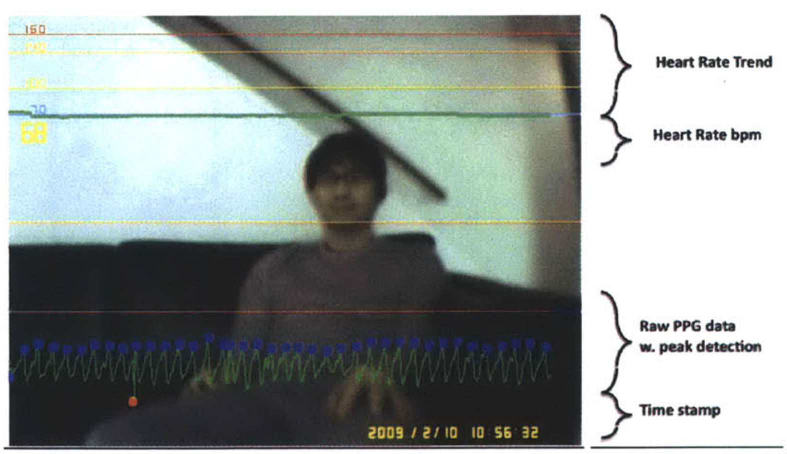

Figure 6-5. Physioboard as a real-time HR trend screen display intervention.

Teacher-rated arousal scores. To investigate how two kinds of physiological displays affected teacher estimation of student arousal, an evaluation form was provided to teacher participants to rate manually how they perceived students' arousal using a 5-point Likert scale ranging from 1 = extremely low to 5 = extremely high. Teachers were asked to rate at the end of each phase.

6.2.4 Environment. An experimental room was set up with incandescent light at the Groden Center. Participants had been to this room many times before. As shown in Figure 4-6, a student participant sat on a comfortable chair. The teacher participant sat facing the student.[34] The investigator was able to monitor the activity through one-way glass and a video camera. Videos were recorded for data analysis only. In these experimental settings, teacher participants faced one of the randomized conditions during the guided relaxation:

1. Physioboard (as "screen display intervention") software was set up on a laptop screen covered by a piece of paper. The computer screen was covered before participants entered the room. The teacher uncovered and covered the screen at the given times.

2. The MiniHeart (as "LED vibro-tactile intervention") was put inside a black bag on the table, as shown in Figure A-6. The MiniHeart was placed in a box and covered before participants entered the room. The teacher uncovered and covered the MiniHeart at the given times.

Unfamiliarity in experimental settings and unfamiliar persons are potential stressors. In order to minimize unfamiliarity, we held workshops with class teachers and our participants.

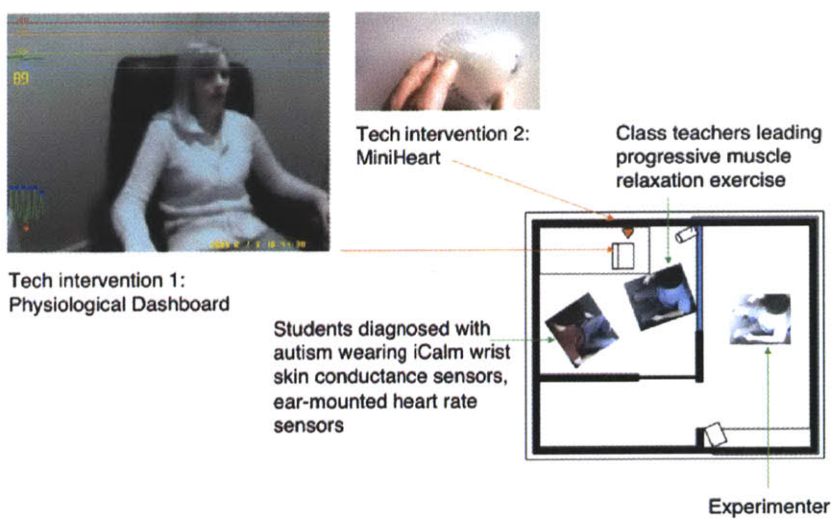

Figure 6-6. The experimenter was able to monitor the activity through one-way glass and a video camera. The student participant sat on a comfortable chair. His/her teacher sat facing the student with a laptop screen on the right side.

[34] Guided relaxation is usually conducted in a face-to-face setting at the Groden center. The teacher finds it easier to prompt the student. In future work, we suggest studying in a different setting where the teacher sits on the same side with the student instead of facing him/her because the student might feel more comfortable without being in front of a person's face.

6.3 Result

6.3.1 Participants. Five out of seven enrolled participants completed 16 out of 34 scheduled trials.[35] Two participants (P05 and P07) were not able to complete any trial and mainly appeared to be averse to wearing the ear-mounted sensor.[36] Five student participants (N=5) and seven teacher participants (N=7) completed 16 trials from May to August 2009. All participants, including the two who did not tolerate the ear sensors, showed no discomforting wearing the wristband iCalm skin conductance sensors. The most frequent reason of not being able to finish the study was an equipment problem, such as hardware and software issues that could not be solved soon enough to keep the study going. Equipment problems indicated that there was a need to have a technical expert present to make sure all equipment was functioning correctly with minimum risks.[37] As show in Table 6-3, a list of the incomplete reasons included:

1. Equipment problems (8 times) stopped the study (e.g., battery ran out in the middle of a trial, computer crashed, ear sensor fell off, the MiniHeart did not respond).

2. Scheduled participants were unable to start due to discomfort with ear-mounted sensor (7 times), as when installation of the sensor caused unease, the participant pulled the ear sensor off, or participant was not willing to wear it.

3. Class teachers halted the study because their students were unable to finish it due to other reasons (3 times).

Table 6-3. Student participants and complete trials

Participant (with coded ID)	Age	Sex	Diagnosis	Trials scheduled	Trials completed
P01	7	Male	Autism(ADOS)	6	3
P02	17	Male	Autism(ADOS)	8	6
P03	10	Male	Autism(ADOS)	6	3
P04	10	Male	Autism(ADOS)	4	2
P05	8	Female	Autism(ADOS)	2	0
P06	14	Female	Autism(ADOS)	6	2
P07	10	Male	Autism(ADOS)	2	0
			Total	34	16

[35] Thirty-four appointments were scheduled for this experiment. If a participant had difficulties in starting or completing, that specific trial would be counted as an incomplete trial. I planned to record six successful trials per participant. However, it was difficult to reach this goal when unexpected conditions occurred, in addition to my own time constrain. I could only successfully record 16 out of 34 scheduled trials.
[36] Part of the IRB approval of this study allowed teachers and participants to stop the trial anytime if needed.
[37] Preventing minimum risks requires basic knowledge of operating electrical devices.

6.3.2 Arousal Externalization. This section describes the data analysis of heart rate (HR) and skin conductance (SC) data measured from the participants. The goal of the data analysis process is to compute *physiological arousal trends* that represent individuals' arousal characteristics as their arousal externalization. Data collection, visual inspection, and statistical analysis are used to process the collected HR and SC data, see Appendix B.

Data collection. Physioboard software collects video, HR, and SC data during each trial on a laptop. Teachers' arousal ratings are collected separated and manually input to a text file. HR data are collected from raw PPG waveform in 12 bits at 20Hz. A heart beat peak detection script written in Python extracts beat-to-beat intervals from a 9-data point window (to capture the data point in a peak on the 5^{th} position). Inter-Beat Interval: (IBI) are averaged in a 10-second moving window as one HR BPM data point for real-time HR trend visualization. SC data points are collected in 10 bits at 2Hz and output as microSiemens. Matlab and R scripts are implemented to visualize aggregated HR, SC, and teachers' rating data points in plots.[38]

Visual inspection. After initial data processing procedures aggregating data from each student participant, investigators visually inspected HR and SC data.[39] Skin conductance data and skin conductance responses (SCRs) activities (e.g., SCR startle responses, SC peaks) varied across dates and participants. Our data showed that low, medium, and high skin conductance activity occurred within the same participants on different dates.

Statistical analysis. When comparing HR and SC data from one phase with another phase, statistical analysis is needed for checking significant changes in mean value. First, time series analysis (TSA) is applied for data such as HR and SC that present strong serial dependencies (Velicer & Fava, 2003). When data points are serial dependent, traditional statistical tests (e.g., T-tests) that assume samples are independent become inappropriate. To remove the serial dependency in the time series, the Auto Regression Integrated Moving Average ARIMA(5,0,0) model is suggested as a general transformation function in order to model the data and to remove serial dependency (Goodwin et al., 2006; Velicer & Fava, 2003). In R, I apply the ARIMA(5,0,0) model to HR and SC data to retrieve mean estimations suggested by the ARIMA(5,0,0) model. Paired T-tests are applied to compare observations of HR mean values (that are retrieved from the ARIMA model) within each adjacent phase and to compare the HR mean in baseline phase with other phases. These repeated observations of phases can induce false discovery rate so p values are adjusted via Benjamini-Hockberg (BH) method (Benjamini & Hochberg, 1995). All hypothesis tests are computed at a .05 significance level.

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[38] I use Matlab for general data processing and R for some special statistical packages (e.g., ARIMA model).

[39] This study mainly focuses on analysis of heart rate because of the conditions of the physiological displays.

Overall (between-participant) comparison in 16 trials out of 5 participants

Overall Heart Rate. An overall comparison across five participants and sixteen trials is calculated, as shown in Figure 6-7. The result shows: 1) no significant difference when comparing the first baseline phase to other phases; 2) no significant difference in mean values between each adjacent phase.

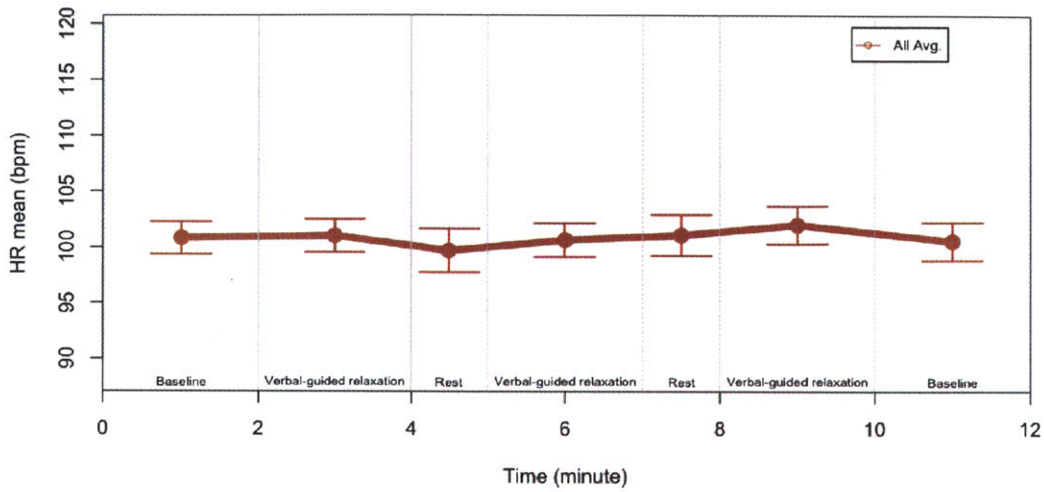


Figure 6-7. Overall comparison of HR mean values of each phase from all participants (N=5, 16 trials) show no significant difference between each adjacent phases and no significant difference when comparing the phase 1 baseline to other phases. Error bar is plotted as ± 1 standard error of mean (SEM).

Overall Skin Conductance. An overall comparison across five participants and sixteen trials is calculated, as shown in Figure 6-8. The result shows: 1) no significant difference when comparing the first baseline phase to other phases; 2) no significant difference in mean values between each adjacent phase.

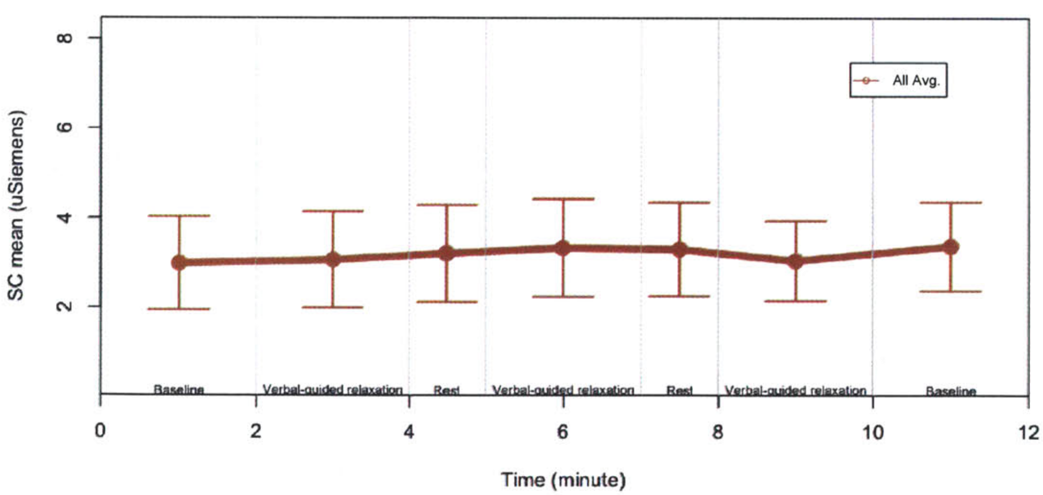


Figure 6-8. Overall comparison of SC mean values of each phase from all participants (N=5, 16 trials) show no significant difference between each adjacent phases and no significant difference when comparing the phase 1 baseline to other phases. Error bar is plotted as ± 1 standard error of mean (SEM).

Participant P02

Heart Rate. In a within-participant comparison for participant P02's HR data, the results show:

1) A significant increase in HR mean ($p<.05$) from the phase 1 baseline phases to phase 2 verbally guided relaxation, significant decreases in HR mean ($p<.05$) comparing phase 1 baseline with phase 3 rest and phase 5 rest, and no significant difference in comparing phase 1 to other phases;

2) A significant increase in HR mean ($p<.05$) from the phase 1 baseline phases to phase 2 verbally guided relaxation, a significant decrease in HR mean ($p<.05$) comparing phase 2 verbally guided relaxation with phase 3 rest, a significant decrease in HR mean ($p<.05$) comparing phase 6 verbally guided relaxation with phase 7 baseline, and no significant difference in HR mean comparing other adjacent phases.

3) The average of P02's HR during the phase 1 baseline is 98.5 bpm. It is still much higher than a typical person's resting heart rate, which is about 70 bpm.

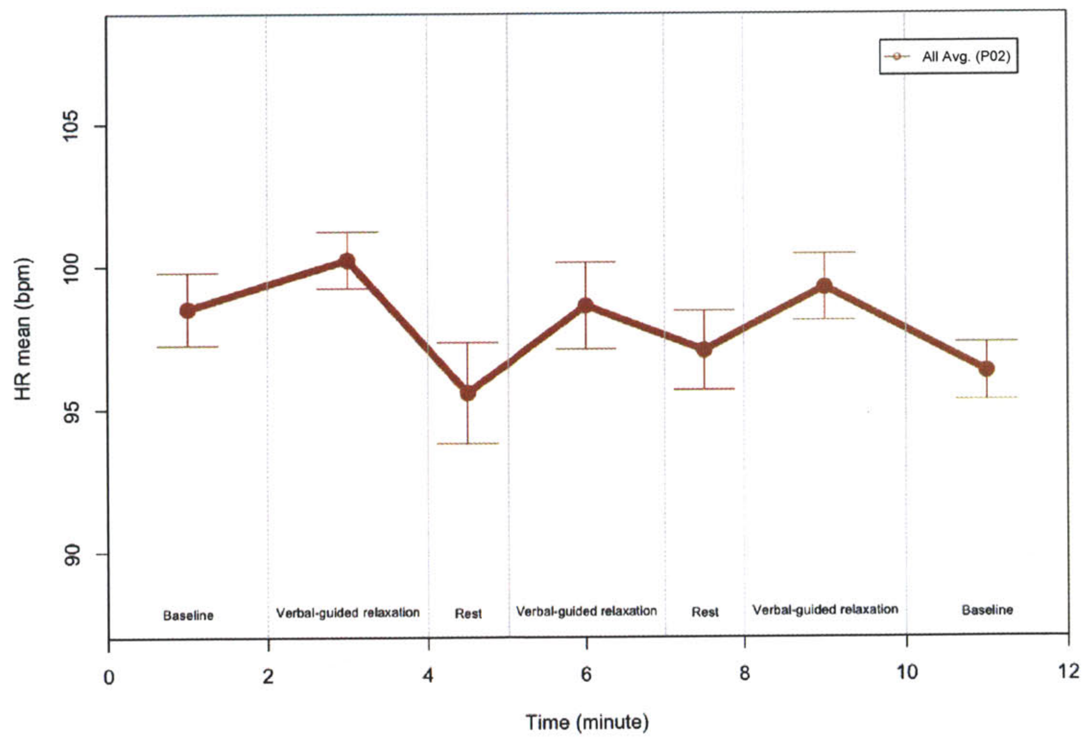
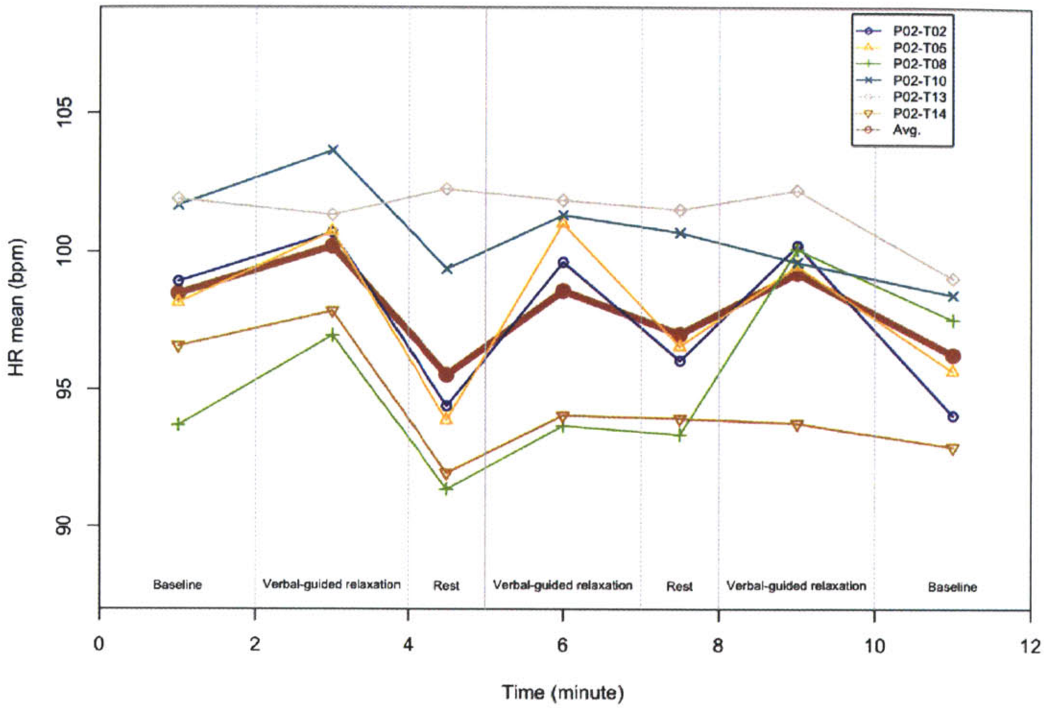


Figure 6-9. Participant P02's HR data aggregated from 6 trials. This plot shows P02 exhibits a visually identifiable pattern of his HR trend. Error bar is plotted as ± 1 standard error of mean (SEM).



	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P02-T02	98.9	100.7	94.4	99.6	96	100.2	94.1
P02-T05	98.2	100.7	93.9	101	96.6	99.5	95.7
P02-T08	93.7	97	91.4	93.7	93.3	100.1	97.5
P02-T10	101.7	103.6	99.4	101.3	100.7	99.6	98.4
P02-T13	101.9	101.3	102.3	101.9	101.5	102.2	99.1
P02-T14	96.6	97.9	92	94.1	94	93.8	92.9
Mean	98.5	100.2	95.5	98.6	97	99.2	96.3
SD	3.1	2.4	4.3	3.7	3.4	2.8	2.5
SEM(n=6)	1.3	1	1.8	1.5	1.4	1.2	1

P02 (6 Trials)	p1p2	p1p3	p1p4	p1p5	p1p6	p1p7
Paired T-Test p=	0.025*	0.013*	0.901	0.021*	0.608	0.137
p.adjust(BH)	0.049*	0.049*	0.901	0.049*	0.729	0.205

*p<.05

P02 (6 Trials)	p1p2	p2p3	p3p4	p4p5	p5p6	p6p7
Paired T-Test p=	0.025*	0.011*	0.039*	0.101	0.126	0.014*
p.adjust(BH)	0.049*	0.041*	0.058	0.121	0.126	0.041*

*p<.05

Figure 6-10. Participant P02's overall HR data between-phases comparison

Discussion.

Participant P02 appeared to have consistently higher HR during verbally guided phases (phases 2, 4, 6) relative to baseline, followed by a lower-than-baseline HR during subsequent rest (no instruction) phases. Several interpretations about this phenomenon can be made. This list is not exhaustive:

First interpretation: The relaxation may not work on P02. After aggregating trials of data of participant P02, one would come to a conclusion that P02 was aroused by the guided relaxation activities so that the relaxation training does not lower P02's HR. Again, we do not intend to make a comment on the efficacy of relaxation in autism. This interpretation can be mistakenly made merely with the analytical result without supporting information. In fact, P02 is the calmest appearing person in this study. He appeared very cooperative and quiet throughout all his trials.

Second interpretation: The relaxation works because P02 showed significant lower HR in the following rest phase. When we look at the first three phases, phase 2 shows significantly higher than the phase 1 baseline and the phase 3 rest. A reasonable interpretation can be made that the verbal guided part of the relaxation may cause cognitive load. When the cognitive part is removed, P02 showed a significant decrease from phase 2's verbally guided relaxation to phase 3 rest. HR in phase 3 rest also shows significantly lower than the phase 1 baseline, which could be the effect of the relaxation after the guided part is over. This interpretation suggests that future physiological assessments of progressive relaxation should take into account cognitive load associated with following directions (i.e., the physiological benefits of relaxation may not be apparent until after a student is no longer engaged in actively attending to a teacher).

Third interpretation: The verbally guided part of the relaxation causes P02 to become alert with elevated HR because P02 is good at following prompts. Based on the second interpretation above, we might be able to say that the relaxation works for P02 when the verbal part is removed. However, during the interviews, teachers reported that P02 was a quiet and prompted person *who follows instructions well.* The elevation of heart rate during the guided relaxation phases may come from teachers' promptings that caused P02 to become alert and attend with increased heart rate. When the promptings were removed in phase 3, P02 show significant lower HR. This interpretation could argue the result that the lower HR in phase 3 is because P02 was not following prompts instead of the second interpretation that the relaxation works after the verbal part is removed. More investigation is needed.

Fourth interpretation: P02's movements during the verbally guided relaxation cause his HR to be higher than during the rest phases. After reviewing videos of P02's trials, I saw that P02 moved his arms and body in order to follow teacher's guidance for the progressive muscle relaxation. This interpretation focuses on P02's movements as the main cause of the higher HR in phase 2.[40]

We can aggregate the interpretations above to make another interpretation: P02's HR is higher in phase 2 because he follows the progressive verbal instructions and he moves his body accordingly to respond to the teacher's instructions. When phase 2 is over, P02 shows a lower HR than the phase 2 and 1 baseline because he is resting without any movement and appears to be relaxing after following the progressive muscle relaxation. This interpretation still leaves a question about whether the guided part or P02's movements cause his higher HR. The analysis of P02's HR arousal trend demonstrates arousal interpretations with physiology-based information. Future work that includes a detailed investigation of how to improve the accuracy of both retrieving and perceiving physiological information in real time seems warranted and promising. Most importantly, more contextual information could reduce misunderstandings around people diagnosed with autism.

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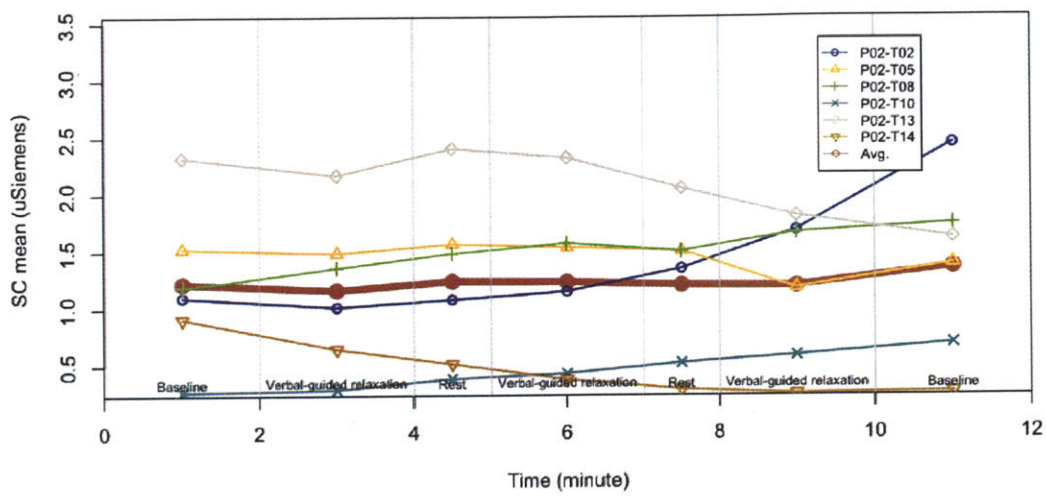
[40] It is possible that P02 had been memorizing the steps of the typical relaxation procedure. Even though the teacher did not instruct him to perform the tensing part of the relaxation, P02 still moved his arms and body to locate the part that he was prompted to tense and to relax. The video shows P02 verbally repeated the "arm, feet, back, stomach" after the teacher's instruction. This could imply the fifth interpretation that P02 was mentally focusing on the typical routine (i.e., doing both tensing and relaxing) so that he repeated what he had been instructed to do before.

Skin Conductance. In a within-participant comparison, the results show: 1) no significant difference when comparing the first baseline phases to other phases; 2) no significant difference in mean values between each adjacent phase. The red line is the averaged SC across all trials. P02's SC data do not show an obvious pattern visually.



	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P02-T02	1.1	1.01	1.07	1.14	1.34	1.68	2.43
P02-T05	1.52	1.48	1.56	1.53	1.5	1.17	1.38
P02-T08	1.18	1.35	1.48	1.56	1.49	1.65	1.73
P02-T10	0.27	0.29	0.38	0.43	0.52	0.59	0.69
P02-T13	2.32	2.17	2.4	2.31	2.04	1.8	1.61
P02-T14	0.91	0.64	0.51	0.37	0.28	0.25	0.26
Mean	1.22	1.16	1.23	1.22	1.2	1.19	1.35
SD	0.68	0.66	0.75	0.74	0.66	0.65	0.78
SEM(n=6)	0.28	0.27	0.3	0.3	0.27	0.26	0.32

P02 (6 Trials)	p1p2	p1p3	p1p4	p1p5	p1p6	p1p7
Paired T-Test p=	0.382	0.863	0.944	0.9	0.91	0.689
p.adjust(BH)	0.944	0.944	0.944	0.944	0.944	0.944

*p<.05

P02 (6 Trials)	p1p2	p2p3	p3p4	p4p5	p5p6	p6p7
Paired T-Test p=	0.382	0.179	0.839	0.678	0.95	0.269
p.adjust(BH)	0.765	0.765	0.95	0.95	0.95	0.765

*p<.05

Figure 6-11. Participant P02's SC data aggregated from 6 trials. P02's between-trial SC trend shows: 1) no significant difference compared to the first baseline; 2) no significant difference compared to adjacent phases.

6.3.3 Behavioral Interpretation. How did class teachers estimate student participants' arousal when one of the three types of interventions (no display, screen display, and LED vibro-tactile) was in presence? This result session shows the comparison (i.e., agreement rate) of teachers' interpretations to the externalization of student participants' physiological arousal. Sixteen completed recordings were collected, including video, heart rate, skin conductance data, and arousal ratings. During the verbally guided relaxation (phases 2, 4, and 6), we randomized the order of three types of interventions (1: no display, 2: screen display, and 3: LED vibro-tactile display) Physiological data were represented to the teacher participants in real-time via a screen-based display and a LED tactile display in order to estimate their students' arousal conditions. Students were blinded to these displays. Interpretation may vary when screen display or LED vibrotactile display was present, as shown in Figure 6-13.

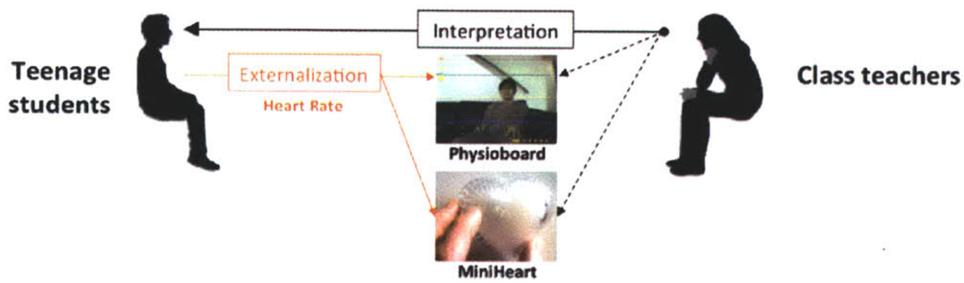


Figure 6-12. Interpretation via no display, screen display, and LED vibro-tactile display

Arousal trends. To investigate how the two kinds of physiological displays affected teacher estimation of student arousal, we compared teacher ratings (using a 5-point Likert scale ranging from 1 = extremely low to 5 = extremely high) with students' HR trend calculated every two adjacent phases. Student HR trend is calculated in two ways. First, I use the mean difference from the adjacent phase (i.e., subtracting the averaged HR from the two adjacent phases). Second, I calculate another HR trend by linearly de-trending the HR data points and then applying Wilcoxon Signed-Rank test (i.e., Wilcox T-test) to see if the HR mean values from the two phases are significantly different.[41]

At the end of each experimental phase, teachers rated their interpretation of students' arousals. The human rating trend is calculated based on teachers' rating. Teachers who knew their student very well[42] rated students' arousal levels according to their past experience of interacting with the participants. In addition, teachers could take advantage of the physiology displays that showed the student's HR status[43] for a more accurate estimation of arousal

[41] The two calculations may result in different outcomes because de-trended mean comparison may change several trends into those not significant.

[42] According to staff at the Groden Center, teacher participants interacted with their paired student participants on a daily basis. Most of them had interacted with the student for at least three months.

[43] MiniHeart displays real-time heartbeats. Physioboard shows averaged HR as a number and the HR trend.

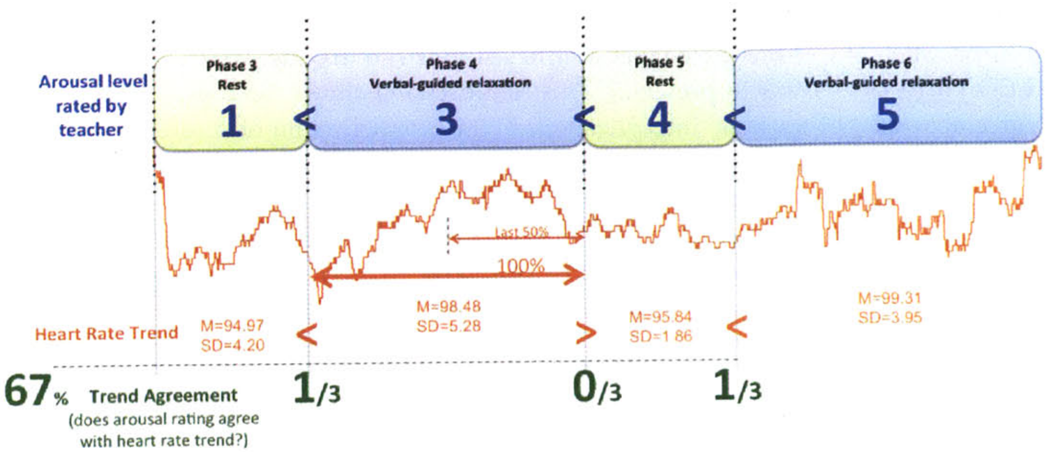


Figure 6-13. Teachers rated how aroused the student appeared at the end of each phase. I calculated the 100% and latest 50% of HR data that could account for teachers' perception of estimated arousal rating.

Agreement rate of human rating trends and arousal trends. When teacher-rating trends match actual student-HR trends, we scored this as 100% agreement. If there were no agreement between teacher ratings and student HR, we scored 0% agreement. Figure 4-21 is an example of calculating the agreement rate. A teacher-rated arousal level 1 in phase 3, 3 in phase 4, 4 in phase 5, and 5 in phase 6. From the data analysis, significant increases in HR were found from phase 3 (M=94.97) to phase 4 (M=98.28) that agreed with the human rating. This example also shows a significant decrease in averaged HR from phase 4 to phase 5 (M=95.84, SD=1.86) that disagrees with teacher's interpretations. From phase 5 to phase 6, the teacher's rating agrees with the increasing HR trend. This example shows two agreements and one disagreement that contribute to a 67% (2 out of 3 matched trend) agreement rate.

Calculating last 50% of HR bpm. The last 50% of student HR data per phase was also calculated in the event that teachers were basing their ratings on the end of phases and not the whole phase. Class teachers were instructed to rate how aroused their students appeared *at the end of each phase*. However, we did not know how much heart rate data accounted for teachers' judgments on ratings. For example, the teacher might rate 1~3 when s/he saw the student appeared calm during the *last* 30 seconds and ignored that the student was anxious at the beginning of that phase. In this case, I take into account of the last 50% of HR data for calculating an arousal trend that could reflect the real-time part of the visual and tactile feedback.

Results. **The results suggest that arousal estimation varies as a function of how physiological information is displayed.** Table 6-4 shows the results of arousal trend and HR agreement rates. HR trend calculations (e.g., 100% vs. last 50% of HR data in the phases; changes in mean vs. de-trend with T-test for changes in mean) were taken into account to test the robustness of our results. The screen display showed higher agreement with teacher ratings than no display across all calculations. Comparing teachers' ratings and students' average HR per phase, we found 77% (70% de-trended) agreement overall when using the screen-based display, 46% (44% de-trended) agreement overall when using the tactile device, 58% (40% de-trended) agreement overall when no real-time data was displayed. Since teachers rated at the end of each phase, we can calculate the last 50% of HR in that phase. In this case, we have 55% (50% de-trended) agreement rate for no real-time data display while screen display is 73% (65% de-trended), and LED vibro-tactile display is 77% (71% de-trended). The agreement rate of teacher rating trends with student skin conductance trends is 31%.[44]

Table 6-4. Agreement rate of trends of caregivers' estimation of students' arousal and averaged heart rate

HR trend calculation / Intervention type	100% HR Phase Mean change	100% HR Phase De-trend t-test	Last 50% HR Phase Mean change	Last 50% HR Phase De-trend t-test
No Display	58%	40%	55%	50%
Screen Display	77%	70%	73%	65%
MiniHeart	46%	44%	77%	71%

A paired T-test is performed to check if the screen display agreement rate is significantly higher than the no-display (i.e., using screen display agreement rates- .77, .70, .73, and .65 comparing with .58, .40, .55, .50). The paired T-test result shows $t(3)=6.25$, $p<.05$. Screen display agreement rate is significantly higher than the no-display agreement rate. The T-test result also shows no significant difference when comparing the MiniHeart agreement rate to no-display, or MiniHeart comparing to screen display.

When using the last 50% of the HR data to calculate HR trend, the MiniHeart display achieved higher arousal trend agreement rates. A two-sample T-test is applied for testing the last 50% MiniHeart agreement rate with no-display (i.e., using .77 and .71 and comparing with .58, .40, .55, and .50). The result shows $t(3.73)=4.69$, $p<.05$; the last 50% MiniHeart agreement rate is significantly higher than no display, but not significantly different when compared with the screen display.

[44] No feedback of skin conductance trend was provided in this study, and participants' SC data varied from .1 to 11 microSiemens during the baseline phase. SC trends in three conditions can be found in the Appendix C.

6.4 Discussion

This experiment is not intended to study the efficacy of progressive muscle relaxation. The progressive muscle relaxation was designed as a way to train students to relax and self-regulate their own arousal. We expect students' arousals would be lower during the guided relaxation phases than the unstructured time-rest phases. However, our data show that not all student participants' HR showed significant decreases during the verbally guided relaxation phases. In this study, we modified the typical routine into a 2-min relax-only verbally guided activity without the tensing part in order to control one relaxation phase for less than two minutes. The typical routine used twice a day is a 3~5 min progressive muscle relaxation. It takes about 20 minutes to go through the original full-body muscle relaxation in a steady and consistent pace. There is another shorter version for some younger children incorporating simple mirroring instructions including relaxing certain muscle groups. Strictly speaking, this modified activity does not meet the requirement as a formal progressive muscle relaxation.

Ear-mounted devices cause some participants stress. In seven out of thirty-four trials, participants were not comfortable with the ear-mounted device. Using contactless physiological measurement could minimize stresses caused by the equipment. A recent development of using Webcams for non-contact heart rate sensing (Poh et al., 2010) could be an ideal alternative for monitoring participant's heart rates without wearable devices.

Seeking standardization in this study was difficult. At school, participants have routines and activities before and after the trial. School activities may arouse students differently. It was difficult to carefully control participants' arousal states before the trial.[45] For future investigation, another ideal experimental environment could be the classroom. The place most familiar to a student outside the home is his or her seat in the classroom. There are possibilities for a variety of physiological devices to be installed on a seat. This enhancement might provide more valuable data about students' everyday lives in a non-invasive way. However, this proposal also raises issues of privacy and filtering noisy data.

When an experiment is conducted within a daily routine, subject maturation could mean our participants got familiar with guided relaxation and rest activities. Subject maturation is one of the threats to experimental validity, meaning that some participants learn and get used to an experiment in repeated trials. In this study, guided relaxation is routinely used in participants' daily lives. If an experiment is conducted *within* daily routines, subject maturation may not be considered as a threat to the experimental validity. Instead, subject maturation of that routine is encouraged from the therapeutic and educational perspectives.

[45] Previous activities could play a very critical part in how aroused participants were during the study. The ideal in-situ experimentation can be a daylong recording that does not rule out any activities at school.

Overall, within-participant and within-trial comparisons provide different viewpoints to arousal externalization. The overall aggregated data among all trials does not present a statistical difference in comparing the first baseline and other phases. However, the within-participant data does provide us clues about one's arousal characteristics (e.g., participant P02 shows significant heart rate increase during the guided relaxation phases). When zooming into the individual trials, we observe the inner states of student participants and interpretations from their class teachers.

Arousal externalization enables a new channel for people with ASD to communicate their arousal. Novel ways of representing inner states are similar to adding English subtitles to a French movie. Having a visible reference to something foreign may reduce difficulties of interpretation. When more clues of a non-verbal individual are exposed and more inner information becomes accessible to people around him/her, the path of learning about this individual widens. In this study, several hidden characteristics emerged as anecdotal information. However, if these characteristics were discovered at their schools, there could be a greater impact on the teachers and families. There could be more school routines accompanied with arousal externalization. This approach empowers special education schools to become places where students' hidden protocols of arousal and behavior could be gradually revealed.

Teacher's interpretations are crucial to regulate students' behaviors. During the study, there were three occasions where teachers halted a trial and told me their students were unable to continue. Class teachers who interact with their students on a daily basis are familiar with students' overt behaviors and possible inner states. Over a period of time, they become better sensors to detect when things have gone wrong with students. There were also several times when I was helping to install sensors on one participant's ear, and suddenly the teacher told me to stop. Detailed observation and quick responses are essential traits of the teachers who always need to make a judgment quickly based on the student's situation. These novel tools, such as Physioboard or the MiniHeart, with functionality to externalize arousals have the functionality to detect if any extreme emotion occurs. When teachers pay attention to multiple individuals, tools that can reduce teachers and caregivers' mental loads are needed for this situation.

Prompting and verbal instructions may be the major factor that induces increased heart rate during the guided relaxation. In 8 out of 16 trials of the study, physiological arousal was significantly increased during the first guided relaxation comparing to the previous phase (2min baseline). To interpret that the guided relaxation induces stress to participants may over-simplify the causal relationships that occurred in this context, especially since we changed the typical relaxation routine in this study. I attempted the following to understand better student participants' characteristics during the guided relaxation:

1. Within-participant comparisons, P02 and P03 had an 80% (4 out of 5 trials) and 66% (2 out of 3 trials) significant HR increase in phase 2, respectively. However, P04 data showed a 100% (2 out of 2 trials) significantly lower HR, while P01 and P06 showed no obvious characteristics.

2. When I was interviewing class teachers, one teacher particularly emphasized P02's traits on "following instructions." P02 always appeared calm and quiet throughout the study. P02 also attended the most trials (total 5 trials and some pilot studies). It was striking to me to see P02's inner responses to the guided relaxation while he appeared the calmest participant at all times.

3. An alternative hypothesis was proposed to inspect what made P02 aroused during the guided relaxation. As P02's teacher mentioned, P02 follows teacher's prompts very well. This may lead to an interpretation that it was the "guided" part catching P02's attention and alertness.

There are still many aspects left for future investigations. For example, it would be interesting to study various prompting styles (e.g., verbal, visual, audio recordings of prompts) during the guided relaxation. A more detailed set of markers and the increasing or decreasing arousals from HR are also needed for better describing personality and behaviors based on physiological data.

6.5 Summary

This lab-based study presented a single-case design experiment with direct replications. Five out of seven enrolled participants completed 16 trials. The two who did not complete the study appeared to be tactilely averse to the ear-mounted sensor. Figure 6-14 is a diagram of how externalization affects interpretations via forms of externalization. Physioboard and MiniHeart were provided to the class teachers for estimating their students' arousal states. Contextual information was collected (i.e., interviews and videos) to study how it could lead to different interpretations. This study can be summarized in two major parts as following.

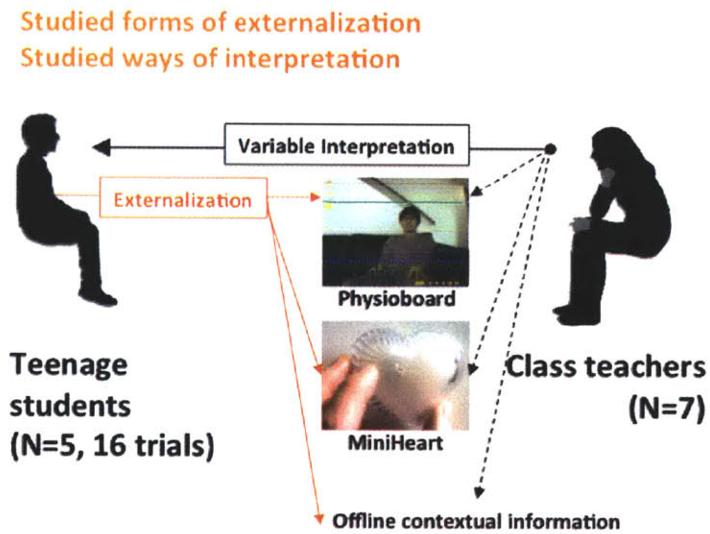


Figure 6-14. Lab-based study investigates forms of externalization and ways of interpretation between teenage students with ASD and their class teachers.

First, how real-time displays, the MiniHeart and Physioboard, of student physiological activity (heart rate) affect teacher estimation of arousal and relaxation. During each phase, the teacher was randomly exposed to one of the three conditions of physiology display (no real-time display, screen display, and the MiniHeart). Teachers rated from 1: extremely low to 5: extremely high on how aroused the student appeared at the end of each phase. The screen display showed higher agreement with teacher ratings than no display across all calculations. Comparing teachers' ratings and students' average HR per phase, we found a 77% agreement overall when using the screen-based display, 46% agreement overall when using the tactile device, 58% agreement overall when no real-time data was displayed. Since teachers rated at the end of each phase, we can calculate the last 50% of HR in that phase. In this case, we have a 55% agreement rate for no real-time data display, while the screen display is 73%, and the MiniHeart is 77%. The results showed that teachers' arousal estimation varies as a function of how physiological information was displayed. The agreement rate of teacher rating trends with student skin conductance trends was 31%, a low value not particular surprising given they had no feedback on SC.

Second, we were interested in understanding how physiological tools could help to characterize and to communicate students' autonomic arousal states. Overall between-phases comparison did not show significant results. However, when comparing within-individual phases, participant P02 presented higher HR during verbally guided phases (phases 2, 4, and 6) from visual inspection. A case study of P02's HR trend reported that there was a significant increase in HR from baseline (phase1) to guided relaxation (phase2), $p<.05$ and significant decreases in HR from the verbally guided relaxation (phase2 and 6) to the next phases (rest and baseline), $p<.05$. P02's HR was higher in phase 2 perhaps because he followed the progressive verbal instructions, and he moved his body accordingly to respond teacher's instructions. When guided phase was over, P02 showed a lower HR than the phase 2 and 1 baseline because he was resting without any movement and appeared to be relaxing after following the verbal guidance. When observing the five participants as a group, our data showed no significant difference when comparing the HR mean value in the first baseline phase with other phases and no significant difference when comparing the HR mean in adjacent phases. This result implies that individual differences of arousal characteristics might disappear in a between-participant comparison.

This study investigated interpersonal arousal interpretations with physiology-based interfaces. Emerging physiological sensors could reveal arousal characteristics during guided relaxation exercises for some people with ASD. Arousal externalization might help teachers more accurately assess their students' internal state and enhance efforts to teach self-regulation. This study also demonstrated that physiological measurement and analysis were able to reveal individuals' arousal characteristics.

Chapter 7

The School-based Study

A clinical-driven approach

Consciousness is rhythmically disposed, because the whole organism is rhythmically disposed. Our consciousness is not a thing separated from our whole physical and mental being.

Wilhelm Wundt, 1912

This study presents a collaboration with an occupational therapist and three teenaged, non-speaking participants diagnosed with ASD. In this study, I document the deployment of the Externalization Toolkit (Chapter 4) and how this investigation helps iterate the design of several tools. I arrived at Giant Steps, CT, a special education school, with my tools. I started with observing the occupational therapy sessions and then introduced a series of physiology-based tools.

From my observations, the occupational therapy seems to be a reciprocal learning process for both the caregiver and participants. During an occupational therapy session, my collaborator, an occupational therapist (OT), observes and evaluates the participant's inner states (e.g., emotion, arousal, motivation). Based on her estimation and experience, she decides what to do next with her participant. If this participant looks less responsive (as in a low arousal state), she guides him to jump on the trampoline in order to stimulate his physiological arousal. If he looks overtly excited or aroused, she carefully leads him to sit inside the beanbag.[46] After that, she brushes his feet and arms in order to keep stimulating his sensory input as well as to help him recover from the arousing physical activity of jumping on the trampoline. Brushing hands and feet is a stimulating but enjoyable activity that most participants accept. At this moment, it is also a great opportunity for the OT to have a conversation with him. When the participant appears calm, the OT brings him to the desk and provides him cognitive tasks. Some are challenging (e.g., Q&A), and some are relaxing (e.g., typing exercises on a computer). This series of activities, as parts of the OT session, are purposefully and carefully organized based on the OT's interpretation and, an equally important element, the participant's sensory capacity.

Sensory integration therapy, as part of the occupational therapy, has been widely accepted by parents as a popular behavioral and educational program for people with ASD (Ayres, 1972). However, its therapeutic function is still controversial and questioned by the scientific community (Baranek, 2002). Dawson and Watling (2000) described that the interventions designed to address sensory and motor impairments have not been validated even though they frequently are found in people diagnosed with autism. In Rogers and Ozonoff's (2005) review in sensory dysfunction research in autism, the lack of methodological standards results in relatively few controlled studies on the efficacy of various behavioral interventions related to treatments of sensory impairments for people diagnosed with ASD. Many studies are considered as quasi-experiments because of the small sample size without a control group.[47] This dissertation is neither intended to study the efficacy of the sensory integration therapy, nor does it provide a claim of treating autism with technological tools. Instead, I want to understand the deployment of the physiology-based tools under practical, real-world situations. There has been little information about how a new technological tool evolves under a natural therapeutic setting (e.g., the OT sessions). With the physiology measurement of autonomic nervous system states, I further investigate how these data serve as arousal references for the OT to interpret the participants' inner states.

The goal for this study is to observe the practice of the sensory integration therapy and to understand how physiology-based tools can provide the most benefits for this practice. I worked with the OT to collect autonomic arousal data from participants (N=3, Age 13~15) via wearable sensors. During the iterative observations, I alter the original tools I brought in order to provide an easier way of communicating the participants' autonomic arousal to the OT and collecting the OT's feedback and interpretations of the participants' behaviors. A total of nine occupational therapy sessions were observed and documented from May to July 2009.

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[46] Trampolines and beanbags are frequently used within Sensory Integration Therapy (Ayres, 1972).
[47] The gold standard of experimentation is to have multi-site, double-blinded, placebo-controlled, randomized control groups. Most studies fail to meet these criteria and are frequently challenged.

I hope to find the best practice in experimenting "within" therapeutic environments for accomplishing the following:

1. Caregivers can benefit from the outcomes of the experiments in the clinical intervention (e.g., is it helpful to communicate participants' skin conductance data as feedback to the caregiver's interpretation?).

2. Caregivers can benefit from reviewing a past behavioral therapy session on an interactive software interface that reconstructs the session from the collected data, such as image snapshots, skin conductance data, behavioral events, and the therapist's comments.

7.1 Motivation

This research studies: 1) characterizing *arousal externalization* using wearable physiological sensors and a screen-based physiological display[48] for inspecting autonomic arousal states; 2) investigating *interpretations* of overt behaviors and physiological measurement; and 3) iterating this investigation to seek a better understanding of the participant, the OT practice, and the alternative functionality of the physiology-based tool that can assist communicating participants' arousal states.

1. *Arousal externalization.*
   How to characterize autonomic arousal states during the occupational therapy sessions? Regulating and tuning arousal is an important aspect in the occupational therapy practice. The OT typically arranges a series of sensory stimulating activities in order to fine-tune observation of the participants' arousal states.

   In this study, I deployed the iCalm wireless skin conductance sensors for measuring skin conductance that reflects the activation of the sympathetic nervous system (Fletcher et al., 2010). These wearable sensors developed by the Affective Computing Group at the MIT Media Lab did not constrain participants' movement so that these tools could be used during physical activities. I implemented Interactive Physioboard, a software interface, for displaying integrated plots of physiological arousal data and video snapshots for representing the participants' arousal states. The OT is able to index and to review the past therapy sessions with time-stamped physiological data in an interactive way.

2. *Behavioral Interpretation*
   How does the OT interpret participants' arousal? How does it differ from the physiological measurement? The OT typically visually estimates individuals' arousal state with her own experience during the OT sessions in order to decide what to do for the next few minutes. I am able to bring in Physioboard software for the

[48] I also attempted to provide a MiniHeart (see Section 3.3.3) to be studied. However, it was difficult to find an appropriately higher-functioning participant, and the prototype stage of the MiniHeart was not durable or user-friendly enough to be used on a daily basis.

OT to review the past therapy sessions. I am curious to see how the OT interprets the behavioral events and how the measured arousal data assist her interpretations.

3. *Iterated investigation*
   There are many unknown factors hidden in the real-world situations. In order to study a new technology deployed in a real-world setting, I observed repeatedly the practical environment and iterated the implementation. This iteration also enabled the OT to review the participants' situations with the physiological data to provide feedback in better understanding the participant. These iterated processes also allowed the OT to organize the activities differently in order to understand certain situations.

7.2 Method

7.2.1 Participants. I collaborated with three non-speaking teenagers with autism[49] and an occupational therapist at Giant Steps, CT. After receiving MIT and Giant Steps IRB approval, we started pilot studies on how physiological tools could be used in monitoring autonomic arousal states in teenagers with ASD. Participants (N=3) were selected by the therapist.[50] The therapist provided the following information about students' behaviors and overt arousal characteristics. The therapist had been familiar with these behaviors in order to provide needed interventions.

> *Participant CL* is a fourteen-year-old, non-speaking, white male with autism. According to the data provided by the OT, when he is over-excited, meaning that he is in a high arousal state, he might laugh excessively, and stand or walk on his toes while flapping his hands. When he is frustrated and anxious, he might say, "All done," squat, or stare at one thing without any purpose. When CL is believed to be under-aroused, he shows flat affect, covers his face, and does not respond to verbal cues.

> *Participant CS* is a thirteen-year-old, non-speaking, white male with autism. When he is over-excited, he waves and flaps his hands or laughs excessively. When he is frustrated, he pinches, scratches, or runs without obvious purpose. When he is believed to be under-aroused, he shows flat affect, no response to language, or staring without purpose.

> *Participant CO* is a fifteen-year-old, non-speaking, white male with autism. He is the strongest one among these three participants. When he seems over-excited, he flicks his fingers, runs or jumps, or makes sounds. When he is frustrated, he might yell "No!" loudly, bite his own hand or wrist, and become aggressive towards others.

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[49] The exact instrument for diagnosing autism was out of record since these non-speaking participants were diagnosed with autism when they were very young before attending this school.
[50] Participants were selected based on availability.

7.2.2 Instrumentation.

Sensory integration therapy. Ayres (1972) developed sensory integration therapy for treating the relation between sensory experiences and motor performance when individuals with ASD are usually being disturbed in sensory processing and having hypo- or hyper-responsiveness to sensory stimuli. Sensory integration therapy is a type of therapeutic intervention aiming to reduce rigidity and stereotyped behaviors. In this study, a sensory integration therapy (e.g., an occupational therapy) consists of multimodal sensory stimulating activities guided by a collaborator, an occupational therapist. A typical sensory integration therapy lasts for 30 minutes and includes sensory motor-based activities that challenge the individual's sensory capacity followed by about 15 minutes of stationary desktop tasks.

iCalm wireless skin conductance wristband sensors. The iCalm wristband measures skin conductance data that reflect the activation of sympathetic nervous system (Fletcher et al., 2010). The OT helps to put the iCalm skin conductance wristband on the participant's right wrist when the occupational therapy session starts. The skin conductance data wirelessly transmits to a nearby laptop in 10bit ADC at 2Hz. A Python script[51] is implemented to receive and process wireless packets from the iCalm sensors and capture video snapshots during the trial. The form factor of the iCalm wristband sensor appears to be more appropriate compared to other wearable sensors (e.g., the ear-mounted heart rate sensor might fall off when a participant jumps on the trampoline).

Interactive Physioboard. This software was first implemented during the pilot study when the OT asked about how to look at the SC data. At the beginning, I did not arrive with this software. I only had a data-collection program that was not intended to be used by the OT. After collecting the first three trials of data, the OT asked how the data looked. I brought a data plot to show a participant's SC data, as shown in Figure 5-1. The OT asked about what made the data go up, go down, or make a spike. I found there was a need to have a software interface for me to communicate better what these data points stand for. In other words, an interactive software interface is desired for representing a therapy session.[52] I started the implementation using Processing while I was on the train back to Boston.[53]

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[51] Python language. See python.org

[52] The sync video and skin conductance function was inspired by a system developed by Shaundra Daily.

[53] It takes 3.5 hours by train from Boston, MA, to the Giant Steps, CT, which gives me some time to develop this interface. Processing is a graphical programming language, see processing.org

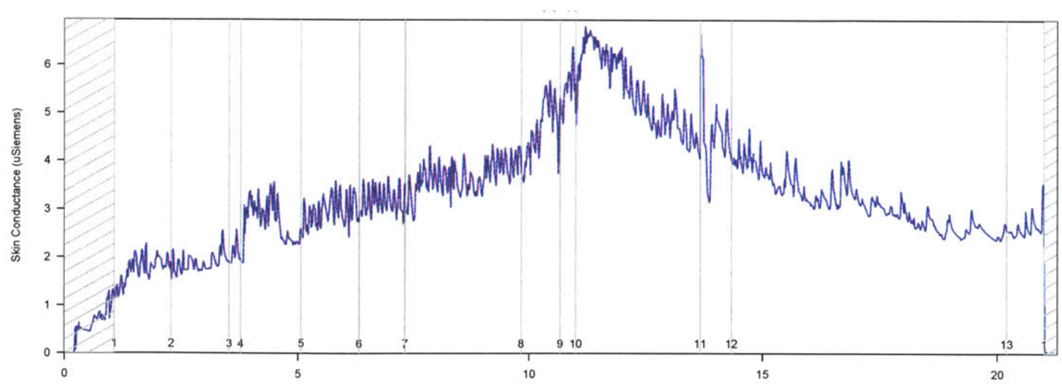

Figure 7-1. A data plot for a participant's skin conductance (unit: microSiemens) in a 20-minute trial. Phases are labeled as numbers at the beginning of each phase.

In the therapeutic environment, an OT session typically consists of a series of interactions based on expectation, verbal guidance, feedback, emotions, and interpretations between the therapist and the participant. However, when a therapy session is over, this important shared experience between them is gone unless another person takes notes or video recordings. There are other methods of observing certain behaviors (e.g., flapping or flicking fingers) by a dedicated staff member counting the frequency of those behaviors as a way to provide a quantitative data over a longer period of time. The qualitative data about the interaction can be an important reference, but it requires the therapist to watch the recorded session and reflect on what exactly happened.

I developed *Interactive Physioboard* to aggregate all collected data (e.g., SC data, video snapshots, behavioral events, the OT's comments) in order to reconstruct the context of a therapy session, as shown in Figure 7-2 (top). I have iterated the implementation during the study. First, it provides the interactive indexing function as a way for the OT to find a sync video frame quickly from a timeline plotted with the SC data. The OT is able to move the mouse cursor on the timeline, and the interface seeks the corresponding video frames in real-time. A simple analytical function is also included for showing the SC mean value and ±1 stand deviation for a customized time period. However, I did not record the audio during the data collection so it lacked an important resource to reconstructing the OT session.[54]

[54] Audio is also a crucial reference to interpret participants' inner states.

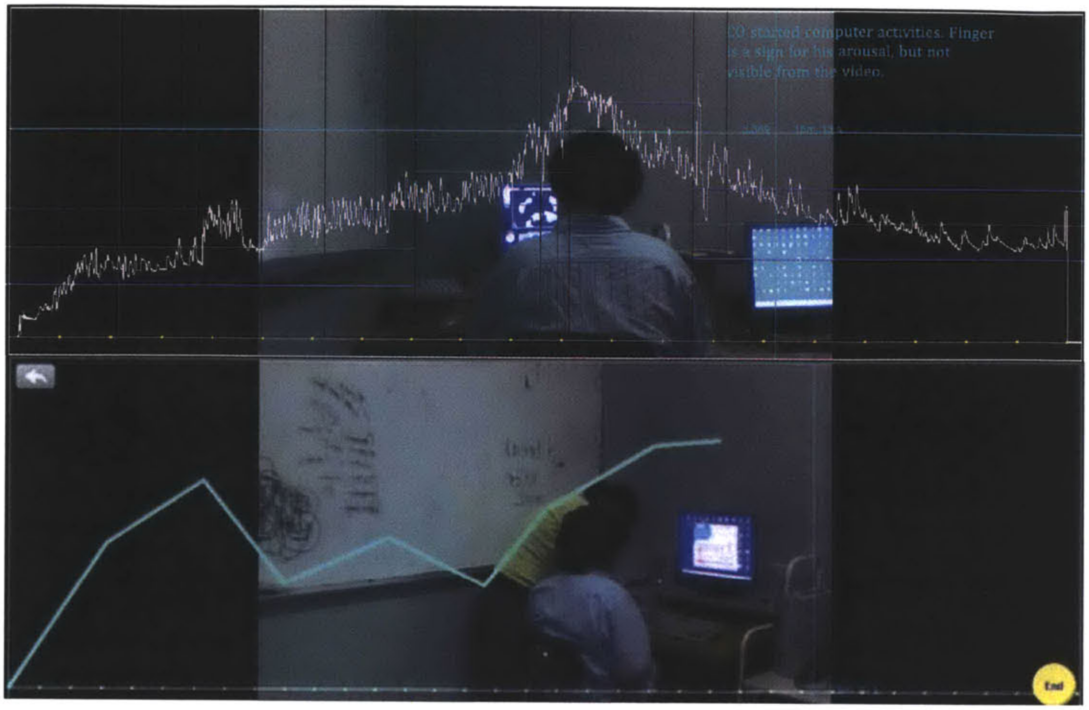

Figure 7-2. (Top) Interactive Physioboard, a data inspection software developed in this dissertation, enables the therapist to review *what is going on inside the subject.* This software interface allows users to index skin conductance data dynamically as pink lines with video data and to place markers as dark-red lines that automatically calculate mean value as green lines and ±1 stand deviation (purple lines) of SC data between each marker. (Bottom) A drawing interface appears for the OT to estimate the participant's arousal.

This interface allows the OT to get a quick overview of what is going on, so I use it as an interview tool. I asked the OT to recall the situation and how she interpreted the participant's arousal. For annotating the OT's estimated arousal, I added a drawing interface for the OT to draw an estimated line, as shown in Figure 7-2 (bottom).

7.2.3 Experimental Design. This study intends to document individual participant's physiological characteristics with contextual information (e.g., photo snapshots, event descriptions, the OT's comments) in occupational therapy (OT) sessions. Each trial is designed to preserve maximum therapeutic function of the intended behavioral therapy. During the OT session, an occupational therapist independently led a series of activities after putting the iCalm skin conductance sensors (Fletcher et al., 2010) on one of the participant's wrist.

I extend ABAB single case design (Kazdin, 1982) by adding physiological tools that constantly sample the participant's autonomic arousal. To analyze each trial, small behavioral phases are used to focus on certain specific behavioral events. Each trial may have variable phases. Phases can be dynamically defined by occupational therapy interventions (e.g., dynamic/physical exercises or stationary tasks), behavioral events (e.g., participant was distracted by noise), or customized needs after the trial, as shown in Figure 7-4. Each phase will have video snapshots, event descriptions, the OT's comments, and skin conductance data. In this study, I compute arousal trends from skin conductance data in the adjacent phases (see next section).

Procedures. The following steps are replicated for all participants.

1. Preparation: the OT evaluates the participant's physical status and plans his/her sensory integration therapy (i.e., activities for tuning and challenging this individual's sensory condition). The OT helps the participant to put on the iCalm wristband.[55]

2. The OT starts the therapy session. The investigator starts collecting SC data and image snapshot data. The OT makes a list of scheduled activities on a small whiteboard and discusses with the participant the order and alternatives.

3. The OT guides a series of activities for a 30~40min session.

4. Trial ends. The OT takes the iCalm wristband off the participant.

5. The OT reviews the video data and rates how aroused the participant appears via Physioboard software.

7.2.4 Analysis. This dissertation presents an analytical method implemented in R[56] for characterizing arousal trend (i.e., skin conductance) in adjacent phases within a trial. Flash phases represent changes between two phases (e.g., one activity/state transiting to another one, or an interruption occurring during an event) that separate the original event into Phase A and Phase B that can be viewed as a miniature ABAB single-case experiment for characterizing arousal and behavioral change. Statistical tests are applied to check if the arousal data from Phases A and B are significantly different. After phases are defined, two adjacent phases are highlighted to check changes in mean, slope, and variation.[57] To characterize SC changes in mean, slope, and variability, I apply analytic methods respectively. For reporting the behavioral events during the OT session, I describe in-situ interactions (Hedmen, 2010/2011 in press) between the therapist and the participant. Another layer of qualitative information from the OT's interviews about the session is added to the behavioral events as OT's comments. Each OT session is presented in a table with behavioral phases and calculations about arousal changes in adjacent phases.

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[55] In this study, the wristband was only on a short time before the therapy session that might not provide enough time for building up moisture around the electrode resulting in very low SC value.
[56] R language. See.r-project.org
[57] Change in variation refers to the startle responses in the skin conductance data, SCR. I calculate SCR per min as peak-per-minute (unit: SCRs/min).

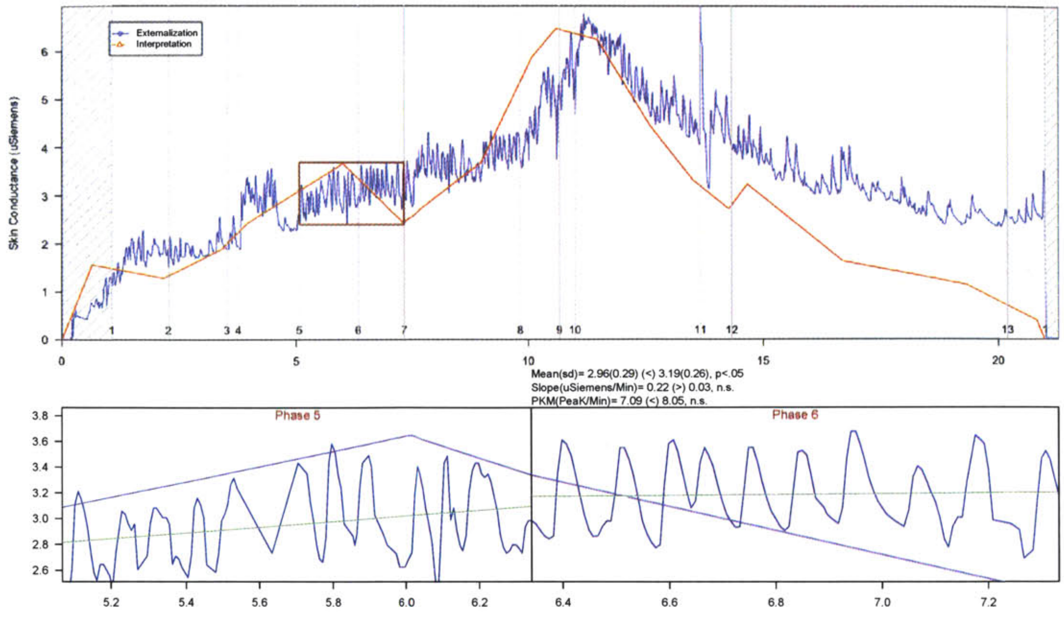

Figure 7-3. A typical OT session is divided into 13 phases. Skin conductance data are plotted as a blue line. The OT's interpretation data are plotted as a red line. The bottom two plots show an analysis of phase 5 and 6, comparing changes in mean, slope, and SC peaks per minute.

For validating changes in mean, I apply time series analysis to the SC data because there is a trend in the SC data points that makes the SC data serially dependent. For example, the previous data point could be used for predicting the following data point. When serial dependency occurs in data, traditional T-tests are inappropriate because T-tests assume each element is independent. I use the Auto-Regression Integrated Moving Average (ARIMA) model to process the time series data points in order to fit this series into a model that removes the serial dependency (Harrop & Velicer, 1985, 1990; Velicer & Colby, 2005). In R, the fitted ARIMA model generates a mean value estimation from the input time series. ARIMA(5,0,0) was suggested as a general transformation method to remove the serial dependency in physiological data (Goodwin, 2006; Velicer & Fava, 2003). R scripts are implemented to fit the original SC data in each phase into the ARIMA(5,0,0) model. I use the mean and variance estimation from the ARIMA(5,0,0) model to calculate a Z-score for the time series from the two adjacent phases. If the Z-score is greater than 1.96 or less than -1.96, it means the mean value of the SC data from these two adjacent phases have statistically significant differences at a .05 significance level.

For validating changes in slope, I apply a linear fit[58] to the two adjacent phases. For checking statistical changes in slope, I calculate the Z-value for checking if two slopes are significantly different. If the Z-score is greater than 1.96 or less than -1.96, it means the slope values of the SC data from these two adjacent phases have statistically significant differences at a .05 significance level.

For validating changes in variability, a SC peak detection algorithm with given

[58] In R, fitting linear model is "lm( )," which also gives a variance.

thresholds (e.g., 0.1 uSiemens in amplitude change) is applied for counting peaks from the SC data. SCR/min is calculated based on the numbers of SC peaks (i.e., skin conductance startle responses) divide total time in minutes in that phase.

7.3 Results

7.3.1 Overall Results.

1. Three participants (N=3, age 13~15 male): CO, CL, and CS (coded name) attended 9 occupational therapy sessions. CO participated 5 sessions; CL and CS attended 2 sessions each.

2. The length of OT sessions ranged from 12.3 to 35.1 minutes (M=25.17, SD=7.24) according to participants' situation and the occupational therapist's arrangement. All sessions consisted of dynamic (physical) and stationary activities.

3. Participants appeared comfortable wearing the iCalm sensors in 6 out of 9 trials.[59] Participant CO took off the wristband once in his forth trial (CO04). CL took off the wristband once in his first trial (CL01) and twice in his second trial (CL02), as illustrated in Table 7-1.

4. Eight out of nine trials showed low skin conductance (SC) tonic level (M < 1.00 μSiemens), except participant CO's fifth trial (M=3.24 μSiemens, SD=1.36 μSiemens) showing active SC responses.[60]

5. Participant CO, CL, and CS were described and analyzed individually (see Appendix D). For each trial, a plot is generated from the participant's SC data and the OT's estimated arousal. A table is generated to represent the trial by its phases. Each phase is annotated with the OT's comments, a basic statistic of the phase (e.g., mean value, standard deviation, slope, and SC peaks per minute), and a comparison with the previous phase for changes in mean, slope, and variability.

6. I attempted to deploy several tools from the Externalization Toolkit. Only a few hardware tools, such as the iCalm skin conductance wristband sensors (Fletcher et al., 2010), were applicable in this real-world environment. The occupational therapy session usually consists of dynamic physical activities. The ear-mounted heart rate sensor (Poh et al., 2010) is not appropriate for activities that include much physical movement. I switched to Polar Heart Rate Wireless Transmitter T31 belt[61] as an

[59] One alternative location of placing skin conductance sensor is on participant's ankle (Hedmen, 2010).

[60] There are several possibilities that SC values are low. The amount of time of wearing the sensor might not be enough because it takes about 10~15 minutes for building up the moisture around the electrodes. Certain anti-stress medication could reduce sympathetic nervous system activity.

[61] Polar Heart Rate transmitter T31 can be found at polar.fi/en/products/accessories/T31_coded_transmitter

alternative wearable heart rate sensor that connects with the MiniHeart. However, I could not find a good fit for an individual to try the MiniHeart because this device requires technical assistance and also requires higher functioning individuals to understand the idea of paying attention to the external heart and feeling the heart beats from the self. At the end, I only deployed the iCalm SC wristband because it appeared to be the least disruptive wearable hardware of which three participants showed no rejection.

Table 7-1. A list of overall stats shows skin conductance varying across trials.

Skin Conductance Level (μSiemens)	Trial 01	Trial 02	Trial 03	Trial 04	Trial 05
CO (15y)	M=0.08 SD= 0.04 T= 23.8min	M=0.14 SD= 0.14 T= 32.0min	M=0.48 SD= 0.54 T=35.1min	M=0.54 SD= 0.50 T=24.4min *(CO took wristband off 1 time)*	M=3.24 SD= 1.36 T=21.3min
CL (14y)	M=0.03 SD=0.01 T=19.9min *(CL took wristband off 1 time)*	M=0.16 SD=0.31 T=12.3min *(CL took wristband off 2 times)*			
CS (13y)	M=0.29 SD=0.13 T=33.1min	M=0.19 SD=0.09 T=24.6min			

7.3.2 Trial CO-05 Study. I will present CO-05 session as a case study of re-constructing the therapy session.[62] Participant CO completed five sessions with physiological measurement. In CO's fifth recorded session, CO presented active skin conductance activities compared to previous sessions (i.e., higher skin conductance value and more startle responses), as shown in Figure 7-4. I analyze this session CO-05 in the following ways:

1. I defined 13 different behavioral events as phases according to video snapshots and skin conductance data. I computed arousal trend of every two adjacent phase for changes in mean, slope, and variation (i.e., skin conductance response per minute—SCR). I documented a list of phases with starting time, event type, basic stats, and arousal trend compared to the previous phase, as

[62] CO-05 is a special example where the behavioral events seem visually related to the skin conductance activities. In CO's four other trials, CO-03 and CO-04 show lower SC value. CO-01 and CO-02 show extreme low SC value. For other trials, I include them in the appendix. Skin conductance activity of a person can perform in very different ways depending on various factors. In 9 recorded trials, there was only one trial CO-05, providing a higher resolution of the SC activity that allowed us to take a closer look on what was going on in that particular session.

listed in Table 7-3.[63]

2. I interviewed the therapist and asked her to estimated CO's arousal level, as the red line in Figure 7-4, by reviewing video snapshots without looking at CO's skin conductance data via the Interactive Physioboard software. The therapist pointed out behaviors that I was not aware of such as CO placing hands closer to his face and flickering his fingers as a sign of anxious or aroused. This interview helped to put together a more detailed event description, as shown in Table 7-3. This table functions as a dictionary of this session. For example, a major SC increase occurs in phase 9 (as shown in Figure 7-4). In Table 7-3, Phase 9 shows the event that CO sits on the trampoline and flicks his finger that usually as a sign when CO is overly aroused. We also need to pay attention to the adjacent phases (i.e., Phase 8 and 10). In this session, Phase 8 shows CO jumps on the trampoline alone that might put him in a high arousal state. In Phase 10, OT notices CO's high arousal state and introduces a calming activity—brushing CO's hands and feet. This indexing functionality is implemented into the Interactive Physioboard where the therapist (or other users) is able to intuitively reviewing video data, SC, and comments in an interactive way.

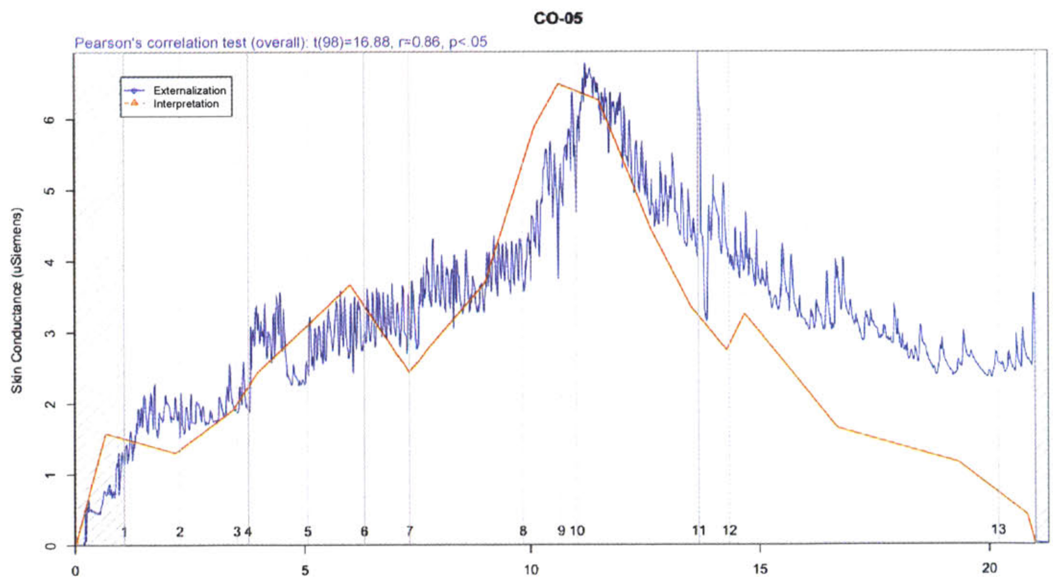

Figure 7-4. Participant CO's Trial 05. CO's SC data is plotted as blue line. The OT's estimation of CO's arousal is plotted as red line. Pearson's correlation test shows t(98)=16.88, r=.86, p<.05. The CO's SC data and the OT's estimation is correlated (r=.86, p<.05).

[63] Event type includes static activities (i.e., sitting, not physically moving around, doing desktop tasks), transition to another activity, vestibular activity (e.g., jumping, sitting or walking on a balancing swing), sensory activity (e.g., listening to audio, brushing hands and feet, massaging), and computer activity.

Table 7-2. CO-05 trial was decomposed into 13 phases.

Phase	Event start (Duration)	Event Description	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend (compared to the previous phase)
1	1m3s (72s)	OT wrote down a list of activities on whiteboard and discussed with CO. CO does flicking fingers that might be an indicator for him to regulate. He sits and smiles.	Static	M=1.74 SD=.26 Slope=.40 SCR/m=8.37	
2	2m15s (75s)	They were about to start the first activity and OT set up the environment.	Transition	M=1.89 SD=.19 Slope=.20 SCR/m=4.82	M: n.s S: decrease P: decrease
3	3m30s (15s)	CO wore weighted vest. Wearing the weighted vest. He likes weighted vest. With the expectation for the trampoline, CO's arousal could be higher.	Transition	M=2.09 SD=.20 Slope=.27 SCR/m=7.98	M: n.s. S: n.s. P: increase
4	3m45s (79s)	OT and CO started jumping. Jumping together can control how fast it's going. The goal is to make his arousal go higher and bring it back.	Vestibular	M=2.74 SD=.41 Slope=-.46 SCR/m=9.09	M: increase S: n.s. P: increase
5	5m4s (76s)	OT and CO started passing ball. Red ball is a weighted ball. Heavy ball is also giving him physical demand. OT thought CO was less aroused than previous activity.	Vestibular	M=2.96 SD=.29 Slope=.22 SCR/m=7.09	M: n.s. S: increase P: decrease
6	6m20s (60s)	OT helped CO take off the weighted vest and CO was sitting on the floor.	Transition	M=3.19 SD=.26 Slope=.03 SCR/m=8.05	M: increase S: n.s. P: increase

Phase	Event start (Duration)	Event Description	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend (compared to the previous phase)
7	7m20s (150s)	They continued passing ball to each other. Some cognitive tasks with ball's position. Switching between weighted and normal ball.	Vestibular	M=3.68 SD=.34 Slope=.24 SCR/m=8.35	M: increase S: increase P: increase
8	9m50s (50s)	CO started jumping on the trampoline by himself. Then he jumps very high alone. OT thought CO's arousal went up.	Vestibular	M=4.70 SD=.57 Slope=1.58 SCR/m=10.99	M: increase S: increase P: increase
9	10m40s (20s)	CO sits on the trampoline and flicks his fingers.	Static	M=5.50 SD=.44 Slope=1.54 SCR/m=3	M: increase S: n.s. P: decrease
10	11m0s (160s)	OT (noticed CO is over-aroused) started brushing on CO's arms and feet. They have conversations about where to brush. Brushing could calm him down.	Sensory	M=5.42 SD=.74 Slope=-.81 SCR/m=7.83	M: n.s. S: decrease P: increase
11	13m40s (40s)	They both left the trampoline and went to the computer room. OT thought the transition could arouse CO.	Transition	M=4.30 SD=.65 Slope=.15 SCR/m=4.54	M: decrease S: increase P: decrease
12	14m20s (352s)	CO started computer activities. Finger activity is a sign for his arousal, but not visible from the video.	Computer	M=3.12 SD=.51 Slope=-.27 SCR/m=5.62	M: decrease S: n.s. P: increase
13	20m12s	CO left computer room.	/	/	

7.3.3 Correlation Test

SC data vs. Interpretation. I interviewed the OT with a simple test that compares the OT's estimated arousal and the measured skin conductance data of the participant. The OT was assisted to draw lines that represented how aroused the participant appears on Interactive Physioboard.[64] The skin conductance data plot appeared after the OT finished drawing lines. During the interview, the investigator posed questions based on her understanding (e.g., "Do you think the student is aroused? Why? Is it caused by physical or cognitive activity?"). Statistical correlation tests were applied to check if the OT and the SC trend were significantly correlated.

	CO.01	CO.02	CO.03	CO.04	CO.05	CL.01	CL.02	CS.01	CS.02
Original sample	0.22	0.39	0.51	-0.01	0.82	0.32	0.2	-0.45	0.7
Re-sample to 100	0.26	0.41	0.53	0.02	0.86	0.28	0.25	-0.54	0.67

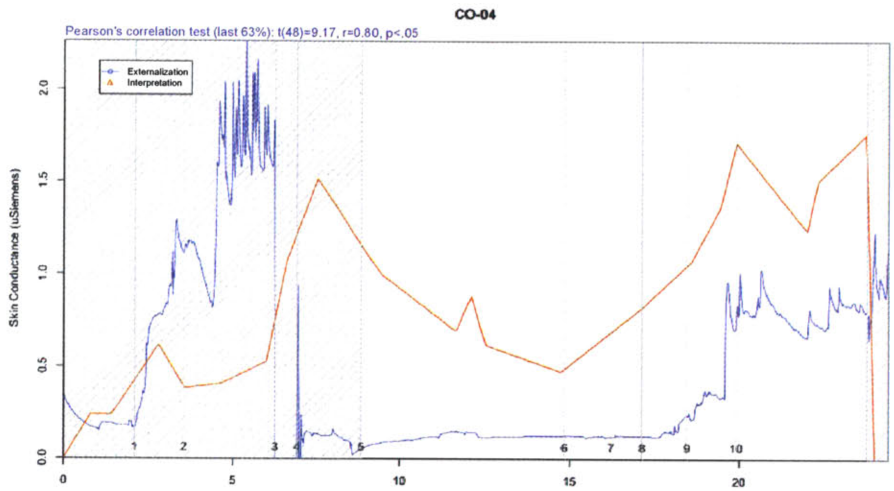

Figure 7-5. (Top) R-value calculated from the Pearson's correlation test comparing the OT's estimated arousal with the skin conductance data. (Bottom) This plot shows participant CO's SC data (blue line), LOWESS smoothing function applied to SC data (green line), and the OT's estimation arousal (red line). The r-value calculated from Trial CO-04 shows not significant, but when I calculate the last 50% of the trial (because the last 50% shows similarly visual form), the r-value becomes .80.

Correlation tests between the OT's arousal estimation (i.e. caregiver's interpretation) and the skin conductance data (i.e., arousal externalization) are calculated. Pearson's correlation test is applied to compare if two datasets are correlated. Each trial has the estimation data and the skin conductance data. Estimation data are about 10~20 data points from the drawing. Skin conductance data are about 1000~2000 data points. I linearly interpolate the estimation data to 100 data points. For SC data, I first apply the LOWESS smoothing function[65] and then downsample SC data to 100 data points. Figure 7-5 shows the r-value calculated from the original sample size without

[64] I was operating the drawing interface and followed the therapist's explanation of student's arousal states to draw lines. I was intended to ease the therapist in operating this software rather than creating a "good" matched result.

[65] In R, LOWESS is a smooth function that uses locally weighted polynomial regression (Cleveland, 1981). I use f=.1 for the smooth span parameter.

interpolating or downsampling the data points. However, the r-value does not change much after re-sampling to 100 data points. Trials CO-05 and CS-02 show .86 and .67 in r-value. Trial CO-04 is not correlated (n.s.) and Trial CS-01 is negatively correlated. Others' r-values fall into .20 to .60. In sum, in 7 out of 9 trials, the OT's estimation positively correlates with the SC data.

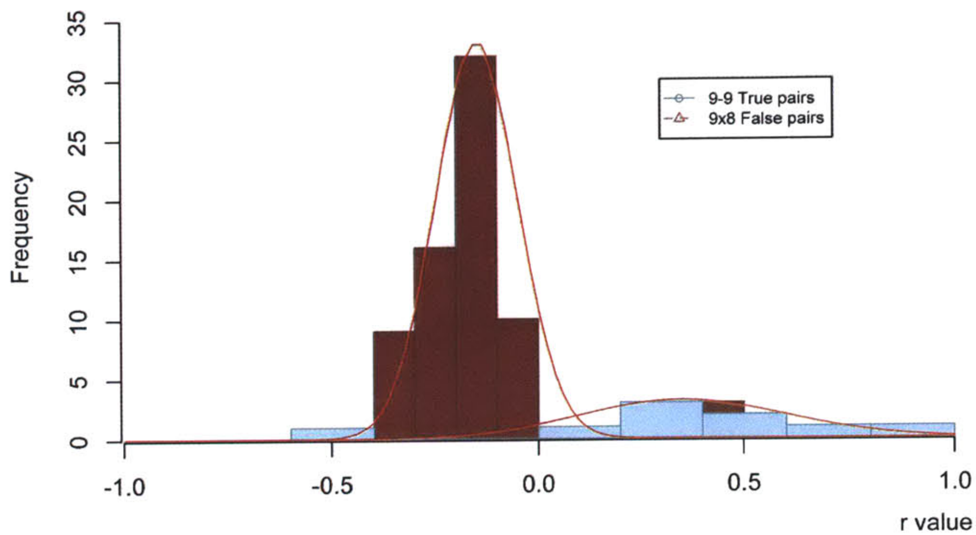

Figure 7-6. R-value calculated from the Pearson's correlation test comparing the OT's estimated arousal with the skin conductance data.

To investigate further if the positive r-values are not caused by chance, I calculate false pairs of correlation (e.g., the correlation between CO-01's SC data and CO-02's estimation data). As shown in Figure 7-6, a total of 9x8 false pairs are calculated and plotted in the histogram as light blue bars. R-values from the true pairs are plotted as red color bars. Most r-values from the false pairs show as negative correlated or not significant, but r-values from the true pairs are mostly scattered in the positive range. This result shows the evidence of specificity that implies the therapist's estimations were correlated with the arousal trend of her participants.[66] Furthermore, we can zoom in to adjacent phases to check if the interpretation correlates with arousal changes in a smaller time frame.

Comparing participant CO's vs. the OT's SC data. What can we learn from the two-interacting persons' SC data? Physiological concordance could imply empathetic interaction in a therapist-patient psychotherapy (Marci et al., 2007). In Kalbe et al. (2007), a psychophysiological study illustrated significant SC elevated when healthy adults read affective stories as opposed to cognitive stories. This may shed some light on why the OT could be affectively resonating with the individual's situation. In trial CO-03 and CO-04, the OT wore the skin conductance wristband too. During these two

[66] The correlation test only functions as a quantitative tool of evaluating the two kinds of datasets. This tool needs to be used together with qualitative interviews in order to have a more thorough understanding of the therapist's interpretation.

trials, I was able to measure simultaneously both the OT's and the participant's skin conductance data. This paired arousal data might provide some insights into the physiological concordance of two interactive roles.

In Trial CO-03, a 34-minute session, the OT's SC presents a low amplitude and slow upward drift throughout the study. Participant CO's data start low and drift upward for 15 minutes. I apply LOWESS smooth function to both dataset and re-sample them to 100 data points before applying the Pearson's correlation test. The result shows t(98)=4.36, r=.40, p<.05, i.e., two data sets are significantly correlated. The .40 r-value could be explained for the first 15-min data drifting instead of causing by the interpersonal interaction. This result and observation implies that positive correlation is not necessarily a valid conclusion if the SC data show low amplitude and drifting.

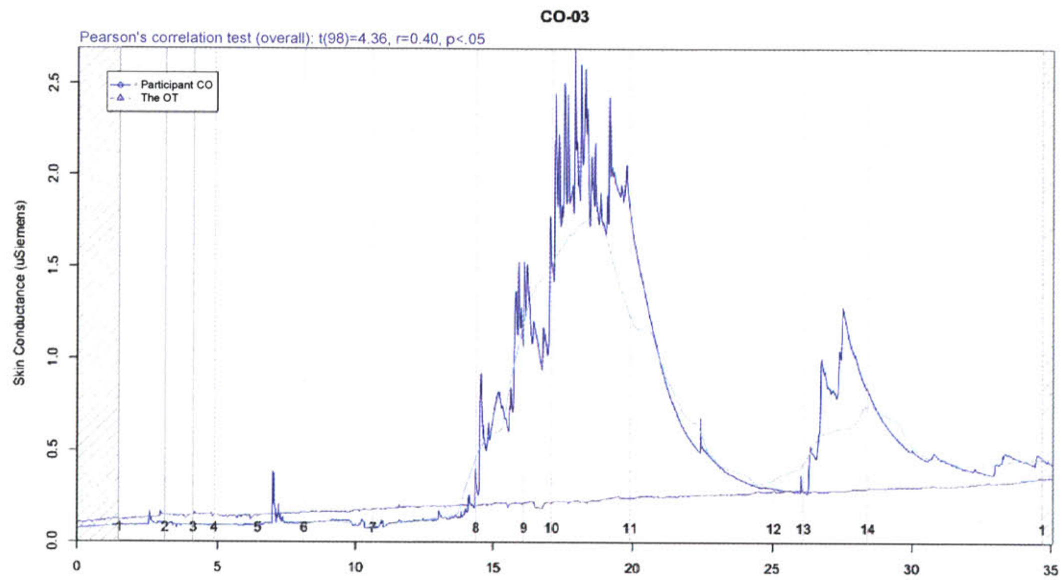

Figure 7-7. In trial CO-03, the SC data shows both the OT (purple line) and CO (blue line) start with low amplitude and drifting. After 15 minutes, CO's SC becomes responsive. The correlation test shows a .40 positive correlation (p<.05) between these two datasets.

In trial CO-04, the OT's SC data start with 1.0 uSiemens, which is about medium amplitude among my observations, and remain responsive with SCR fluctuations till the end. CO's SC data start with low amplitude at .40 uSiemens and show SCR fluctuations at 4~6 minute, but CO took off the sensor for a minute which causes it drop to a low value on the new dry skin. After wearing it again, CO's SC data show low amplitude below .50 uSiemens for 12 minutes, but show SCR fluctuations from the 19th minute till the end. Pearson's correlation test for the overall data shows t(98)=5.88, r=.51, p<.05; the two datasets are positively correlated. However, as we understand, CO removed the SC wristband around the 6th minute and put it back on again, which could be the reason for another low-amplitude drifting for 12 minutes. This analysis implies that for a detailed investigation of physiological concordance of interpersonal interaction, we need to have enough data to rule out the outliers in order to have a cleaner data to look at the two interacting arousal data.

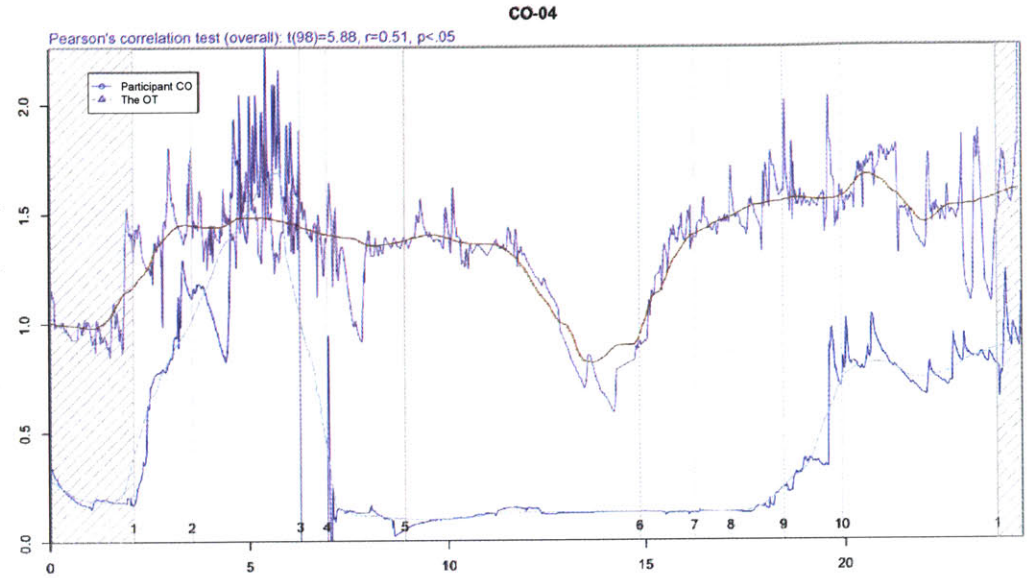

Figure 7-8. In trial CO-04, the SC data shows both the OT (purple line) and CO (blue line). The correlation test shows a .51 positive correlation (p<.05) between these two datasets.

7.4 Discussion

Can sequences of interventions be manipulated to discover participant's arousal characteristics? The OT and the investigator intentionally manipulate the activity (e.g., keep the participant waiting for his favorite activity). From CO's trial 02, the OT and I found an interesting phenomenon that CO's SC data show a big increase when CO was waiting for the computer program to start. In the following trial 03, as shown in Figure 7-9, the OT placed a special condition that the computer program was not smoothly launched in front of the participant. We found participant CO's skin conductance (SC) rose dramatically when he was anticipating the computer program would launch.[67] In trial 05, when the computer program launched smoothly, participant CO's SC data presented decreasing physiological arousal with descending skin conductance tonic levels and fewer skin conductance responses (SCRs) than previous activities in this session.

[67] Participant CO was sitting quietly when his skin conductance rose significantly.

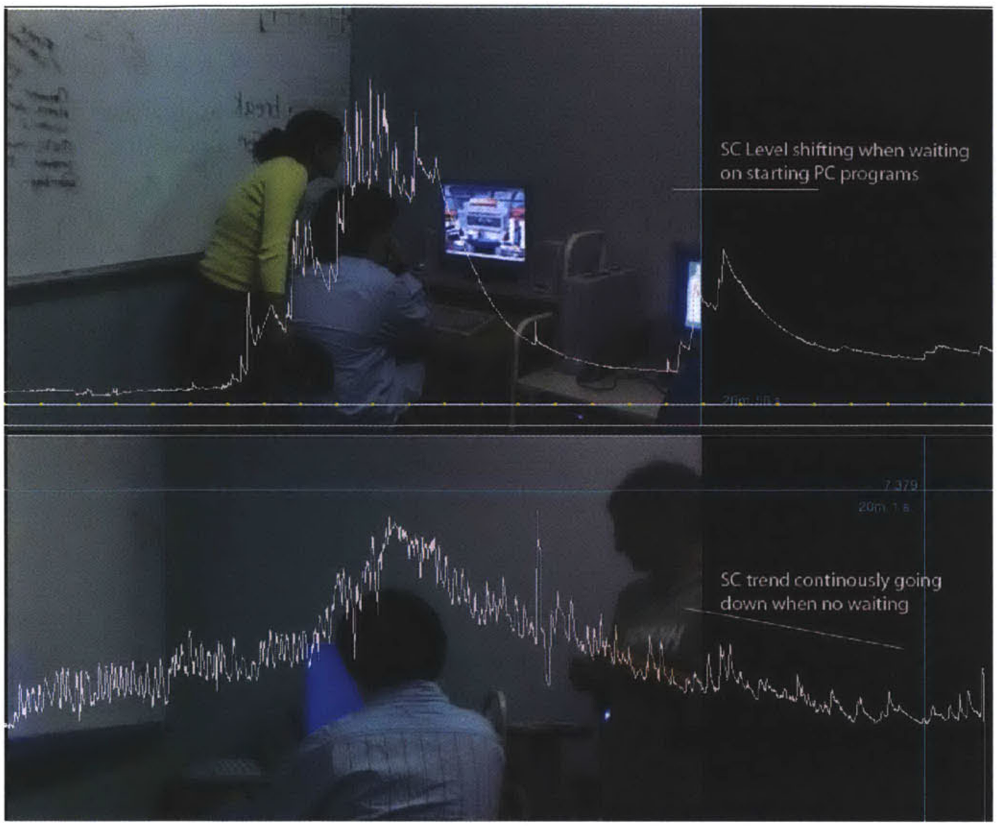

Figure 7-9. In participant CO's Trial 03, the OT intentionally made the computer program (one of CO's favorite activities) launch slowly. We found participant CO was anxious with increased skin conductance tonic level. In Trial 05, when the computer program launched smoothly, CO's SC showed a decrease with fewer SCRs.

How does this study tell us more about the participant? In this study, participant CO completed five sessions. I found the following characteristics that could be taken for further investigations:

1. CO's skin conductance data showed more phasic (startle) responses when he was jumping on the trampoline (CO-01-phase5, CO-02-phase4, CO-05-phase4). One possible interpretation was the increased physiological arousal caused by physical activities. During sensory stimulating interventions (brushing hands and feet in trial 04 and 05), CO's SC showed increased SCR startle responses (i.e. skin conductance peaks per minute). In trial 05, CO's SC data showed an decreasing tonic trend but increasing startle (phasic) responses. However, in trial 01 and 03, CO's data showed low SC activities (lower tonic level and no SCRs) when experiencing physical or sensory activities.

2. CO's SC showed decreasing tonic level and fewer skin conductance responses when starting his favorite computer program, the "typing exercise" (e.g., in trial 05, when CO started typing, his SC showed fewer startle responses than previous phases). When CO was waiting for computer to start, his SC data showed a big increased in trend and tonic level in trial 03.

Can this tool provide "real time" arousal information to the OT practice? In this study, skin conductance wristband sensors were deployed, and we analyzed the data *after* the study in order to preserve maximum therapeutic function of the OT sessions. Providing real-time information *during* the study may enable OTs to respond immediately to participants' situations. However, it may also distract OT's practice because the OT has to pay full attention to the participant. In this case, the OT is not able to mark the overt arousal events on her own. It requires another dedicated staff with similar expertise to monitor and to mark behavioral events.

How can we systematically analyze physiological data (e.g., skin conductance) addressing one's individual difference? This study demonstrates the following steps: first, raw interpretations on changes in levels, trends, and variability (i.e., phasic responses) can be made. For example, if there is a significant increase in skin conductance trend during an event, we can interpret that this event may be a possible cause the participant's "arousing" or "increased skin conductance for 0.4 uSiemens/min" (Hedmen, 2010/2011 in press). Second, we need to have more data of the context. For example, CO is jumping on the trampoline and there is a significant increase in his SC. We could interpret that jumping on the trampoline relates to one possibility of activating CO's sympathetic nervous system. Another example, when CO sat in front of the computer and waited for the program to start, CO's SC showed a significant increase, which could be caused by the anticipation or impatience, both of which activate the sympathetic nervous system. After the computer program launched, CO's SC data showed a decrease in tonic level, meaning that there was less activation from the sympathetic nervous system.[68]

Can each OT session become a legitimate experimentation? Possibly. With reliable tools and recognized methodologies, each OT session is not only a treatment tool, but also a scientific instrument with quantitative measurement to treat and discover individual arousal characteristics. In addition to the quantitative measurement, OT's experiences and comments are also a crucial qualitative reference in order to construct a more holistic understanding of an individual. This dissertation presents this school-based study as a starting point for the mix method quantitative and qualitative approach to therapeutic activities. In this study, a technical assistant was required for data processing (e.g., solving hardware issues, collecting and visualizing data, doing other trivial computer tasks). To solve this human resource problem, one of the extended works may involve making easier software interface. The current version of Physioboard required a computer technician to operate. To overcome this, I envision a Website or a mobile app that could provide needed functions so that the OTs are able to use the software easily on their machines without a technician in order to be deployed without a dedicated technician.

[68] There may be other unseen causes of the increased sympathetic nervous system activation (e.g., a stomach ache, pain, or some other stimulus)

Physioboard reconstructs the OT sessions that become a form of accumulating the interpersonal knowledge of the OT and the participant. During the interviews, the investigator used Physioboard with the OT to estimate how aroused her participant appeared. The investigator posed questions about the participant's behaviors, and the OT responded in a detailed matter about her strategies and interpretations in fine-tuning her estimate of the participants' arousals. After the estimation, the true skin conductance trend showed up on the screen overlaid with the interpreted arousal line. The OT and the investigator discussed the estimations and also discovered several possible interpretations across sessions. With these assumptions found during the estimations, the OT illustrated several points (e.g., if participant CS is in a high arousal state, having fewer transitions and keeping him engaged in a single activity for longer period could better regulate his arousal) where she would include them in her future practice with these participants. The OT also highlighted the interpersonal relationship as part of the therapeutic functions in the practice. Because of the accumulated interactions with her participants, the OT is able to understand her participants and modulate their arousal in minutes. With more tools helping this interpersonal investigation approach, it is possible to create an impact on the existing care-giving and therapeutic practices.

7.5 Summary

This study presented a mix of quantitative and qualitative approaches to discover individuals' arousal-behavioral characteristics under therapeutic settings (i.e., sensory integration therapies) in an iterative manner. As shown in Figure 7-10, I collaborated with an occupational therapist (OT) and three participants (N=3, non-verbal ASD) in nine occupational therapy sessions. I brought prototypes of Externalization Toolkit and deployed my tool at a special education school, the Giant Steps, CT. The participants wore a sweatband with wireless sensors for collecting physiological data (skin conductance). I studied how physiological data (i.e., skin conductance data) helped the therapist to interpret the students' arousal states via interviews. Statistical analyses were also applied to compare arousal trend in adjacent behavior events. This study also demonstrated that physiological data could be collected in clinical settings without compromising experimental aspects.

The OT was interviewed and asked to review the therapy session and to estimate each participant arousal trends. A statistical correlation test was applied to compare the OT's estimation and the arousal data. The results showed that the OT's estimations in four out of five of participant CO's trials are positively correlated ($r=.22, .39, .51$, and $.82$, $p<.05$); in one out of two trials of CS are positively correlated ($r=-.45$ and $.70$, $p<.05$); and in two out of two trials of CL are positively correlated ($r=.32$ and $.20$, $p<.05$). Causes for these correlations were also discussed.

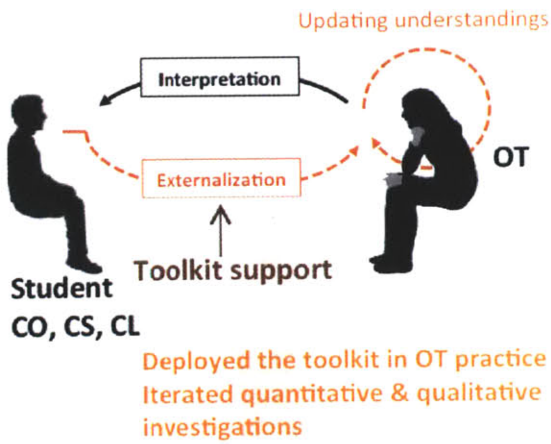

Figure 7-10. School-based study deployed Externalization Toolkit in the occupational therapy sessions with iterated investigations.

For characterizing participants' arousal during therapy, smaller phases were defined by behavioral events. Analysis was applied to skin conductance data in each adjacent behavioral phase for comparing changes in level, trend, or variation (e.g., startle, phasic response). This analysis provided several physiological facts to behavioral events that could help caregivers to convey participants' arousal characteristics. Not all trials present active skin conductance activities that can be easily inspected visually. In most trials (8 out of 9), the skin conductance activities are very low (Mean < 1μSiemens). The one trial (i.e., CO-05) with higher skin conductance amplitude shows obvious data patterns from visual inspection. A case study of analyzing the CO-05 trial was included.

This approach demonstrated how externalization could be used to enhance interpretations of an individual's arousal states. I envision this approach can be widely used for examining and comparing physiological responses within a series of dynamic activities. More importantly, this study implies that similar technologies and methods might empower people who interact with individuals with ASD in a more naturalistic environment such as at school or home. This alternative method of investigating physiological characteristics could help parents, caregivers, and schoolteachers to gain greater understandings from hidden arousal facts.

Chapter 8

Conclusion

"Experience is never at fault; it is only your judgment that is in error in promising itself such results from experience as are not caused by our experiments."

— Leonardo da Vinci, 1510

Externalization of autonomic arousal could make communication reflective, especially when communication channels are limited. For non-verbal individuals diagnosed with autism spectrum disorder (ASD), many assumptions of their social and emotional behaviors are established on the basis of biased understandings, i.e., their appearance. This research started with a literature survey of three kinds of efforts to understand autism, individual difference, evidence-based research, and clinical-driven therapy. In real-world situations, caregivers interact with this special population where many hidden stressors might cause atypical behaviors. With physiological measurement from wearable and wireless sensors, we are able to investigate arousal characteristics of certain daily routines (i.e., the progressive muscle relaxation and occupational therapy sessions) at the special education school. More importantly, this dissertation studied how caregivers could use physiological tools as a way to assist their interpretations in order to understand and support individuals diagnosed with ASD.

To systematically understand the processes of social understanding, this dissertation drew a framework from a series of theoretical models such as modeling communication, modeling other's inner states, and modeling supportive interaction. This framework of social understanding was used in investigating a home-based, lab-based, and school-based study. Figure 8-1 summarizes these three investigations as diagrams of externalization and interpretation.

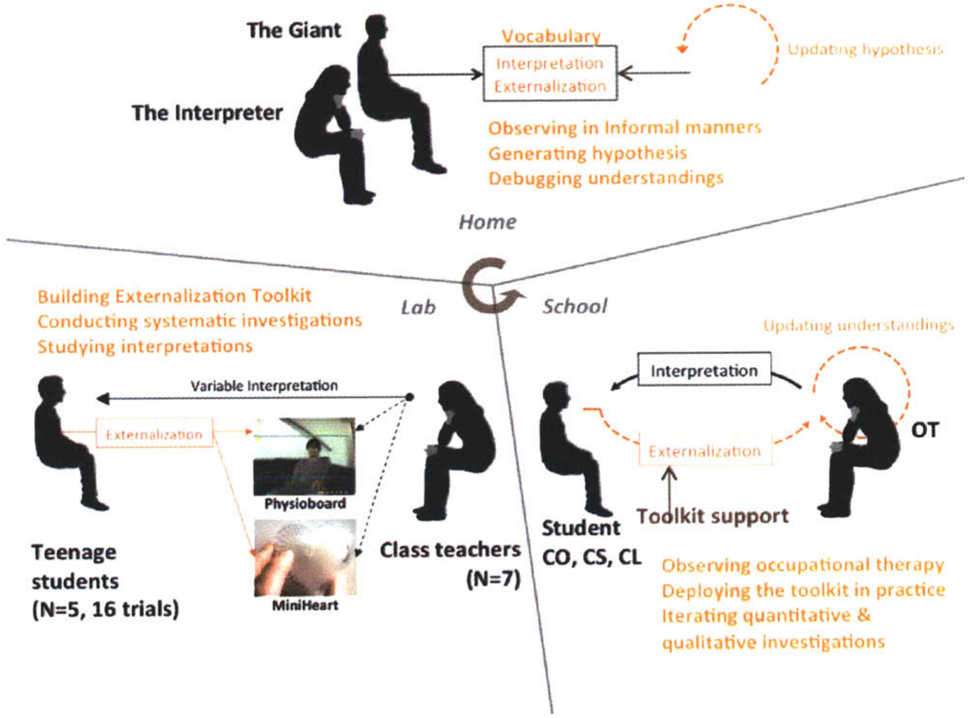

Figure 8-1. The three chosen approaches investigate the ingredients of understandings: externalization and interpretation.

The home-based study, a participant-driven study, reveals the needs of investigating misunderstandings *within* everyday life. This study presented an ethnography of detecting misunderstandings in a family with a young man with ASD who did not speak the way most people usually do. I took close observations and did ad-hoc studies to learn about the hidden protocols of overt behaviors and inner states. Before establishing my understandings of this young man (the Giant), I was relying on this mother's explanation of the Giant's inner states. In this exploration with the Giant and his mother, the Giant's special interests of tearing paper, watching videos, and painting started transforming to special elements of a vocabulary leading to form a special dialogue with him. During the process, I constantly updated my hypothesis about this special social interaction as well as my understandings of the Giant. A vocabulary has been slowly accumulated between him and me after a series of attempts of interpreting his inner states and behaviors. This investigation provided an alternative way of understanding the processes of knowing an individual with ASD.

When interpreting inner states in people who do not communicate in typical ways, I construct a set of physiology-based technologies as an Externalization Toolkit that helps make an individual's autonomic arousal data accessible and reusable. I attempted to help caregivers to perceive individuals' physiological information with the MiniHeart and Physioboard as part of the toolkit. Two studies investigated the processes of externalizing and interpreting autonomic arousal states: 1) The lab-based study (N=5, 16 trials); and 2) the school-based study (N=3, 9 trials).

The lab-based study was a single-case experiment with direct replications based on a modification of progressive muscle relaxation (PMR). I sought to understand, first, how participants' inner states (i.e., physiological arousals measured by wireless heart rate and skin conductance sensors) could tell us how effectively the PMR worked on them; second, how teachers perceived their students' inner states with and without technological assistance. The results showed that: 1) all student participants presented a high heart rate throughout the study (higher than 90 bpm) and different skin conductance activities (e.g., one participant exhibited high, medium, and low SC in his three trials); 2) The screen display (Physioboard) showed higher agreement with teacher ratings than no display across all calculations. Comparing teachers' ratings and students' average HR per phases, we found 77% agreement overall when using the screen-based display, 46% agreement overall when using the tactile device, and 58% agreement overall when no real-time data was displayed. When considering the real-time feedback aspect that teachers rated at the end of each phase, the results showed a 55% agreement rate for no real-time data display while screen display is 73%, and MiniHeart is 77%; 3) individuals' arousal data showed that one participant (i.e. participant P02) had a higher heart rate in most of the verbally guided relaxation phases. I did an in-depth exploratory study on how interpretations of participant P02's inner states could be made differently with given information (e.g., HR, teacher's rating, images, video). In addition, when performing within-participant comparison, our data showed several significant changes between phases. However, when we aggregated all the participant data together, the overall comparison of phases did not show the significant changes found within the individuals. This comparison points to the importance of doing idiographic analysis in this heterogeneous population. Our results also show that teachers' arousal estimation varies as a function of how physiological information is displayed. Interpretation also varies as a function of how detailed information is available.

The school-based study, a caregiver-guided study, presented the results of interpreting autonomic arousal states from three non-verbal individuals with ASD in nine occupational therapy sessions during the school day. An occupational therapist arranged sequences of sensory and motor activities that fine-tuned participants' arousal during the occupational therapy (OT) sessions. With the Externalization Toolkit for documenting the OT sessions, the therapist and I worked together in observing and interpreting three participants' arousal characteristics. The Interactive Physioboard enabled the therapist to review skin conductance (SC) data in an interactive way and comment on behavioral events. The results of the correlation test between the therapist's estimation and the arousal data showed, first, the OT's estimations in four out of five of participant COs' trials are positively correlated ($r=.22$, $.39$, $.51$, and $.82$, $p<.05$); in one out of two trials of CS are positively correlated ($r=-.45$ and $.70$, $p<.05$); and in two out of two trials of CL are positively correlated (r=.32 and .20, p<.05). Second, by between-adjacent-phase comparison, in-situ profiles of arousal characteristics were constructed with analysis of skin conductance data for changes in mean, slope, and variation in adjacent phases. In this study, the therapist and I also found opportunities to investigate certain specific situations. For example, when the participant CO sat in front of the computer and waited for his favorite typing program to launch, the CO's SC showed a significant increase. This study demonstrated a novel way for caregivers (e.g., occupational therapists) to characterize individuals' arousal-behavior protocol as well as to transform OT sessions into individual single-case experiments. Along with this discovery, I alternated both exploratory and confirmatory approaches in order to seek out evidence that could enhance caregivers' interpretations of participants with ASD.

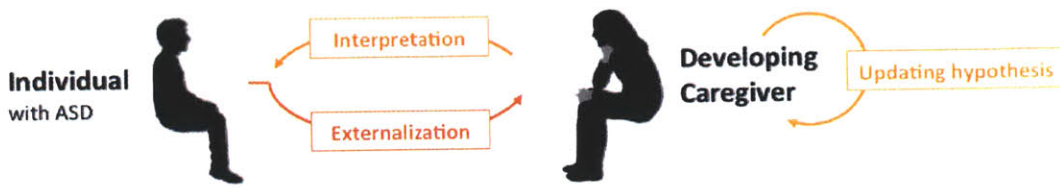

Figure 8-2. The model of detecting misunderstandings consists of the strategic interpretation loop in the caregiver and the externalization from the recipient.

This dissertation emphasizes on empowering caregivers to communicate arousal in daily situations with physiological tools in order to double-check their understandings of arousal-behavioral relationships in individuals with ASD. From the home-based, the lab-based and the school-based study, a series of the processes of externalization and interpretation can be summarized into the model of detecting misunderstanding, as shown in Figure 8-2. The individual's externalization is an important information resource for the caregiver to update his or her hypothesis. In everyday life, a loop between externalization and interpretation could reinforce the understanding of the recipient. With the assistance of physiological information as part of the externalization, the caregiver could make interpretations in a more precise way in tracking over-aroused behaviors.

This dissertation demonstrates examples of strategic interpretation as methods and the Externalization Toolkit as a tool to understand in school routines, occupational therapy sessions, and family situations. If any caregiver or technological developer interested in discovering hidden misunderstandings with non-verbal individuals in their everyday lives finds this work relevant, this dissertation will have served its purpose.

Chapter 9

Future Work

Towards quantitative social understandings

Establishing social understanding is a lifetime business. This dissertation has attempted to address the processes of social understandings between a caregiver and an individual with ASD as a framework consisting of three layers—theory of mind layer, information layer, and personality layer, as proposed in Chapter 3. In the information layer, externalization helps to provide an objective reference to other forms of messages as a way to reduce misunderstandings. This framework could potentially help to discover more interpretations of atypical messages with autonomic arousal data. In addition, this framework can be applied to any situation of communication.

There is a strong need for a generic physiology-based time series modeling solution for collecting, processing, and analyzing multimodal data for a given time span (i.e., a trial), but it could also be extended with future trials (e.g., same participant with multiple trials). This goal is to combine all the data processing efforts illustrated in this dissertation into one extensive solution. In the lab-based and school-based studies, raw data of each trial have been collected via various means (e.g., HR was collected in 12 bit 20Hz PPG waveform; SC was 10 bit 2Hz; teacher rating was 1 to 5 at the end of each phase). In addition, behavioral events and therapists' comments could also add to the raw dataset that could reconstruct the recorded session. A series of data analytic techniques has been made in this dissertation (e.g., using time series analysis ARIMA model to estimate mean value; using Pearson correlation to compare human estimation with arousal measurement). When deploying these tools and analytical methods to real-world usage, it is important to have a generic data processing framework for storing these important data in order to reconstruct the session when needed

In the school-based, clinical-driven study, I calculated the correlation of the caregiver's cognitive estimation with the skin conductance trends that might imply how accurately the caregiver perceived the participant's inner states (i.e., autonomic arousal states). More importantly, these comparisons provided feedback to the caregiver about her observations. Through repeated measurement, it would be possible to unveil other hidden understandings that could be accumulated as the caregiver's library of how to perceive someone's arousal states. This approach is also helpful for the support group (e.g., parents, caregivers, doctors) to debug and consolidate their understandings of an individual. As more evidence of behavioral and autonomic arousal linkages is revealed, we will be more confident in identifying false interpretations because of the increasing accuracy from arousal externalization (e.g., more accurate, durable, and comfortable sensors for 24/7 recording). A longitudinal study is suggested to focus on the intensive loops of quantifying social understanding with qualitative communal interviews.

In the home-based participant-driven study, I, as an ethnographer, investigated biases and assumptions that can disrupt the reciprocal interaction between the non-verbal young man with ASD and me. The goal of this study can be extended to construct an interpersonal channel, such as seeking a dialogue using a newly established language. The feedback will be subtle, but not unobservable. The young man's mother has already demonstrated her experience with noticing subtle clues that might be able to lead to a conversation. The next challenging step is how we can keep, track, and re-use elements with which he has responded. These elements might eventually become a vocabulary for understanding and interacting with this young man. Another question can be raised: can this vocabulary help a new person to know and to understand the young man in a shorter period of time?

In the Externalization Toolkit, individuals could use these technologies for self-regulation and biofeedback. This toolkit should further enable its users to collect their own data and formulate these data as applications (i.e. recognizing relevant data patterns) for real-world situations. In addition, simultaneous physiological recording of both caregiver and recipient may also reveal interpersonal interaction in action.

Externalizing is more than a means to assist communication as an alternative channel. Externalization shifts the human-to-human communication beyond its verbal and visible components. The outcome of externalization could enrich the value of communication and provides opportunities to move forward with common understandings. I envision that anyone can be empowered as a detective with physiological tools in order to understand people beyond the typical communication channels and appearance.

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Appendix A.
MiniHeart Visual Perceptual Study

Questionnaire

Title of Study:
Autonomic Arousal in Autism Spectrum Disorders:
Measurement, Communication, and Characterization

Procedure:
You will be asked to estimate BPM (Beats Per Minute) of one pulsing LED within 8~12 seconds for 10 times. Please underline the range of your estimation of BPM and rate the confidence level (1~5) you feel about your estimation after each trial. (Confidence Level: 1. Least confident, 2. Less confident, 3. Neutral, 4. Confident, 5. Very confident)

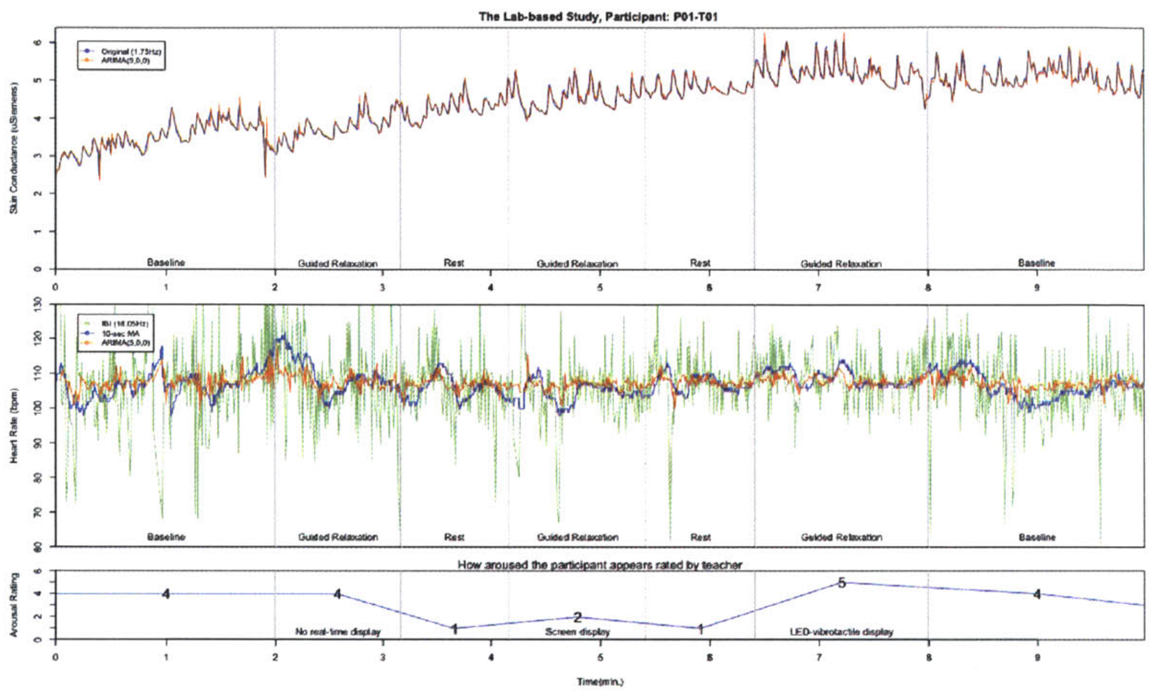
											Confidence Level
test)	60	70	80	90	100	110	120	130	140	150 (BPM)	______
1)	60	70	80	90	100	110	120	130	140	150	______
2)	60	70	80	90	100	110	120	130	140	150	______
3)	60	70	80	90	100	110	120	130	140	150	______
4)	60	70	80	90	100	110	120	130	140	150	______
5)	60	70	80	90	100	110	120	130	140	150	______
6)	60	70	80	90	100	110	120	130	140	150	______
7)	60	70	80	90	100	110	120	130	140	150	______
8)	60	70	80	90	100	110	120	130	140	150	______
9)	60	70	80	90	100	110	120	130	140	150	______
10)	60	70	80	90	100	110	120	130	140	150	______

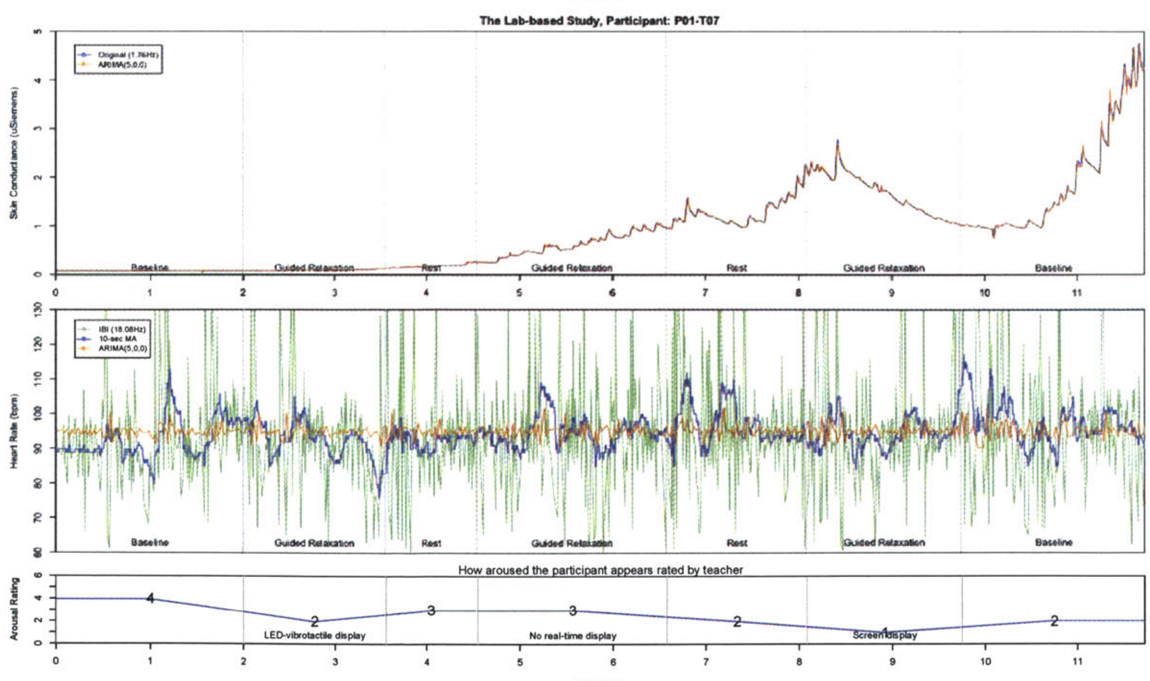
Thanks for participating in this research.

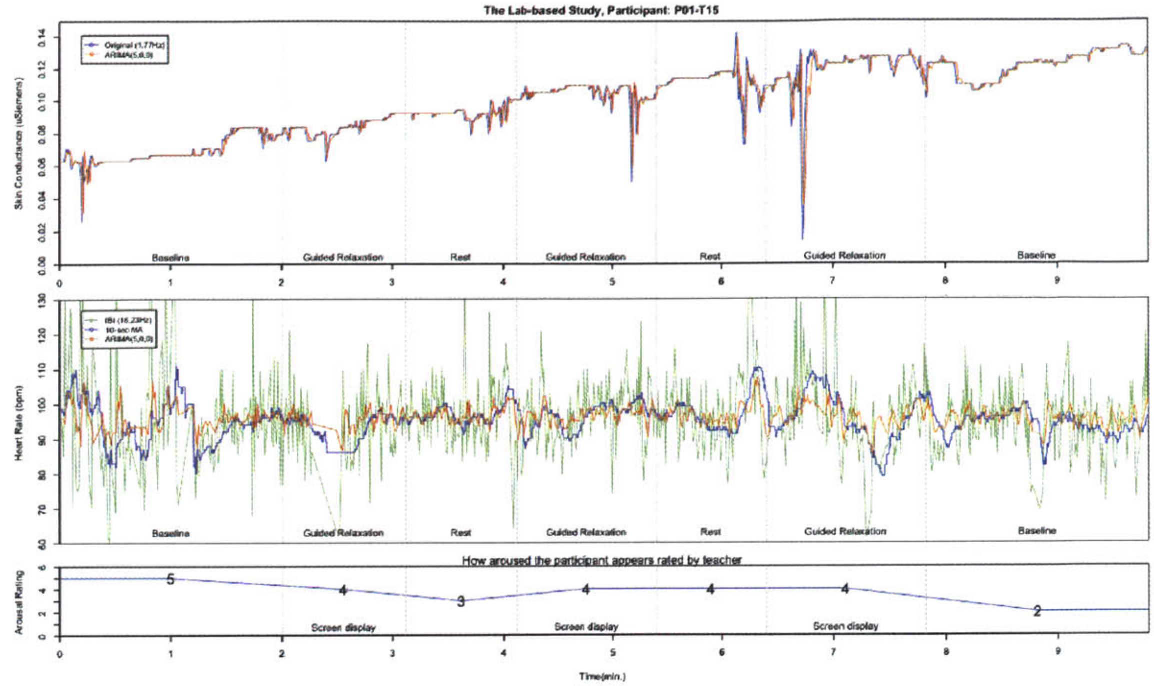
Appendix B.
The lab-based Study data plots

Participant P01

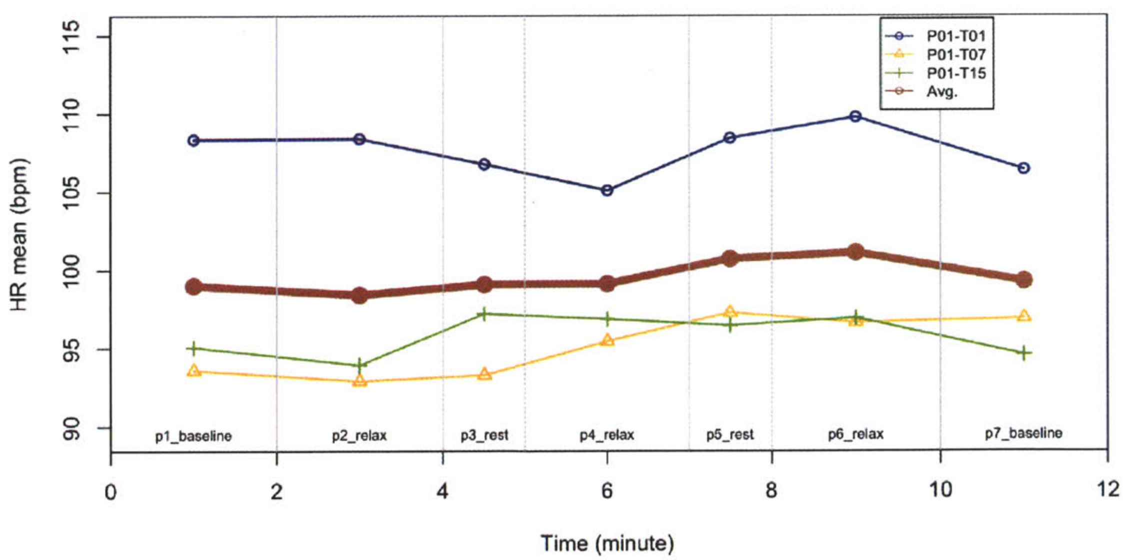
T01, T07, and T15 trials







P01 Heart Rate Trend (3 trials)



P01 Heart Rate mean value estimation from ARIMA(5,0,0) in R

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P01-T01	108.4	108.4	106.8	105.1	108.4	109.8	106.4
P01-T07	93.6	92.9	93.3	95.4	97.2	96.6	96.9
P01-T15	95.1	93.9	97.2	96.8	96.4	96.9	94.6
Mean	99	98.4	99.1	99.1	100.7	101.1	99.3
SD	8.1	8.7	6.9	5.2	6.7	7.5	6.3
SEM(n=3)	4.7	5	4	3	3.9	4.3	3.6

P01 Heart Rate trend comparison:

No significance was found when comparing phase 1 baseline with other phases. In R, I adjusted p value using Benjamini-Hochberg (BH) method because multiple hypothesis tests on the same dataset cause more false positives (i.e., an increase false discovery rate in repeated measures).

P01 (3 Trials)	p1p2	p1p3	p1p4	p1p5	p1p6	p1p7
Paired T-Test p=	0.224	0.947	0.953	0.25	0.051	0.877
p.adjust(BH)	0.5	0.953	0.953	0.5	0.305	0.953

*p<.05

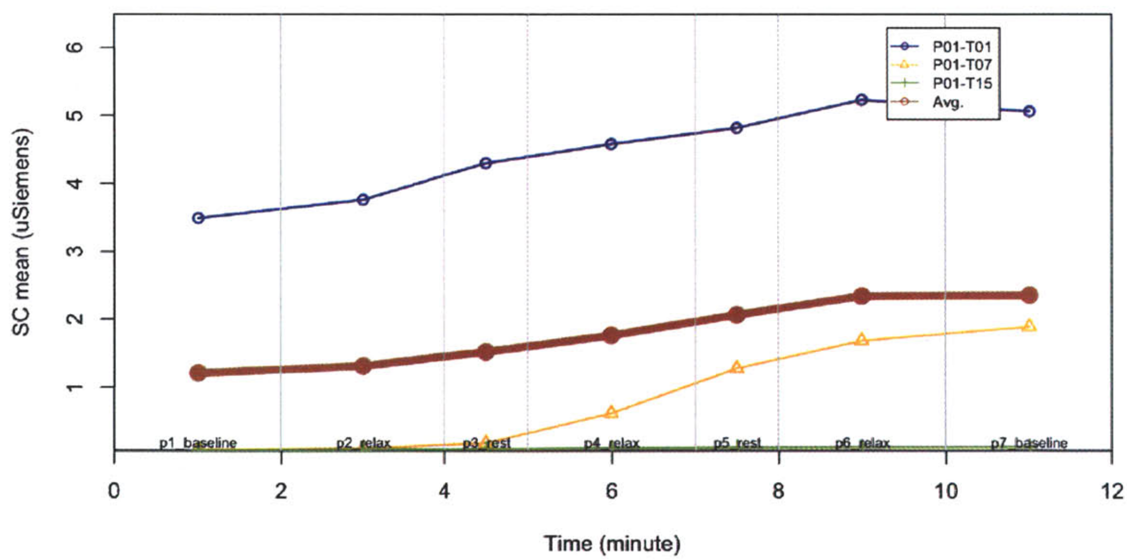
P01 Heart Rate trend comparison:

No significance was found when comparing every adjacent phase.

P01 (3 Trials)	p1p2	p2p3	p3p4	p4p5	p5p6	p6p7
Paired T-Test p=	0.224	0.681	0.981	0.285	0.556	0.234
p.adjust(BH)	0.569	0.818	0.981	0.569	0.818	0.569

*p<.05

P01 Skin Conductance Trend (3 trials)



P01 Skin Conductance mean value estimation from ARIMA(5,0,0)

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P01-T01	3.49	3.76	4.3	4.58	4.82	5.23	5.06
P01-T07	0.09	0.1	0.18	0.62	1.28	1.69	1.9
P01-T15	0.07	0.08	0.09	0.1	0.11	0.12	0.12
Mean	1.22	1.32	1.53	1.77	2.07	2.35	2.36
SD	1.97	2.12	2.4	2.45	2.45	2.62	2.5
SEM(n=3)	1.14	1.22	1.39	1.41	1.42	1.51	1.44

P01 Skin Conductance trend comparison:
No significance was found when comparing phase 1 baseline with other phases.

P01 (3 Trials)	p1p2	p1p3	p1p4	p1p5	p1p6	p1p7
Paired T-Test p=	0.355	0.34	0.21	0.171	0.172	0.173
p.adjust(BH)	0.355	0.355	0.315	0.315	0.315	0.315

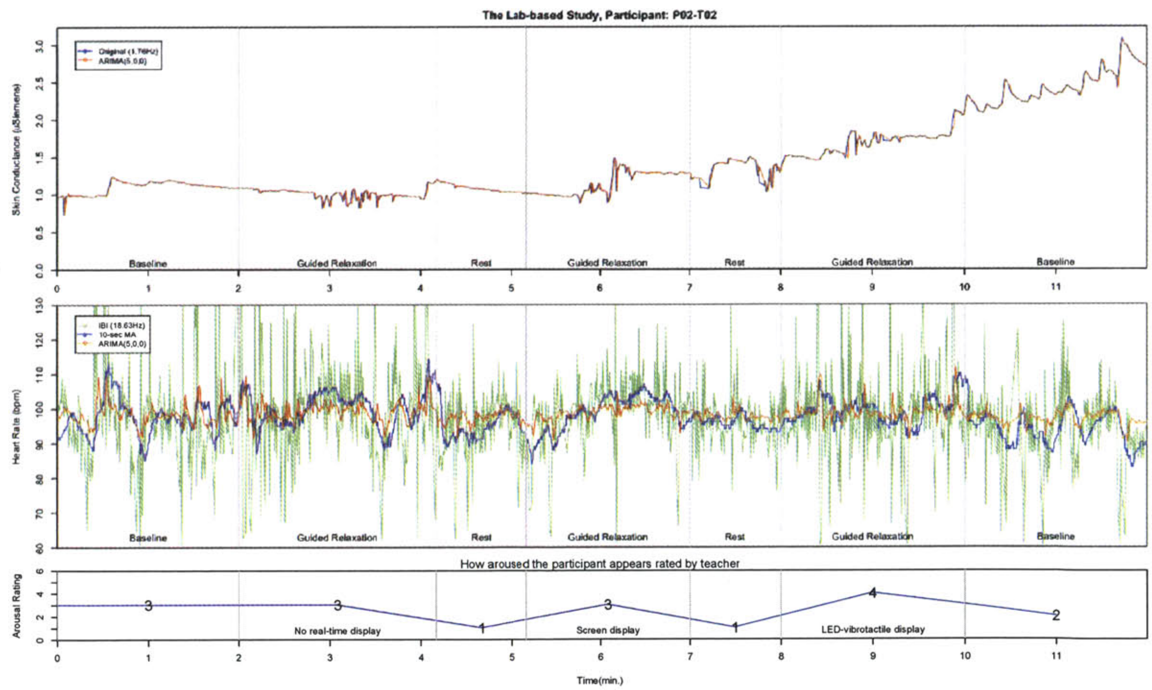
*p<.05

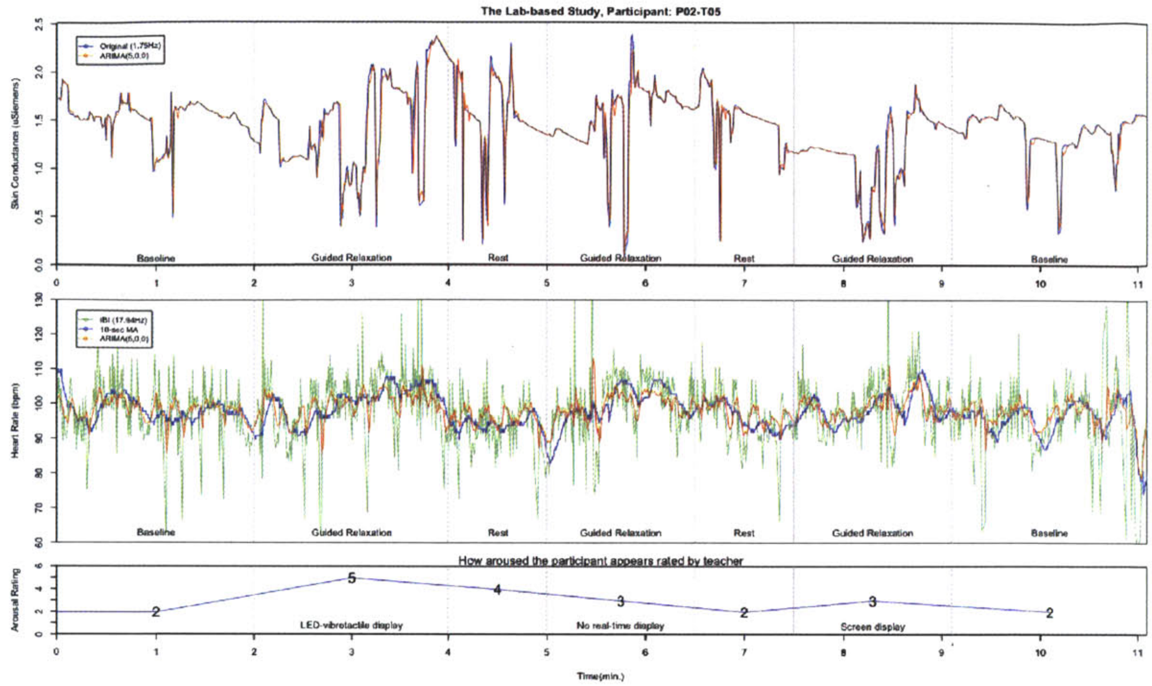
P01 Skin Conductance trend comparison:
No significance was found when comparing every adjacent phase.

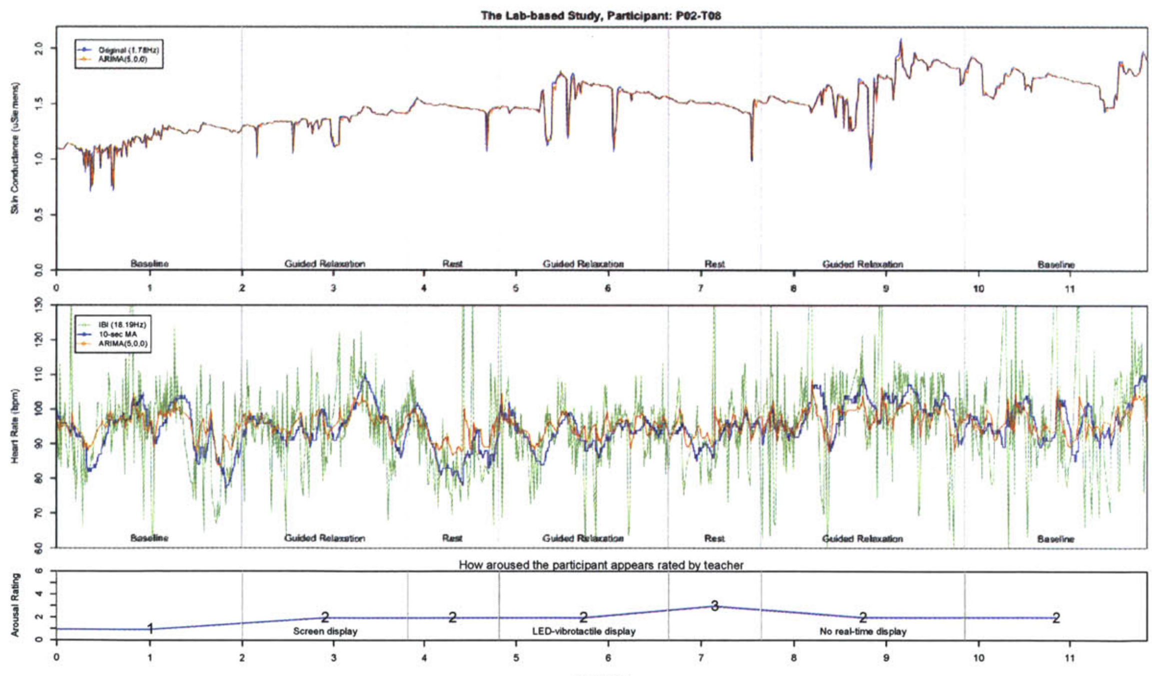
P01 (3 Trials)	p1p2	p2p3	p3p4	p4p5	p5p6	p6p7
Paired T-Test p=	0.355	0.334	0.189	0.255	0.177	0.921
p.adjust(BH)	0.426	0.426	0.426	0.426	0.426	0.921

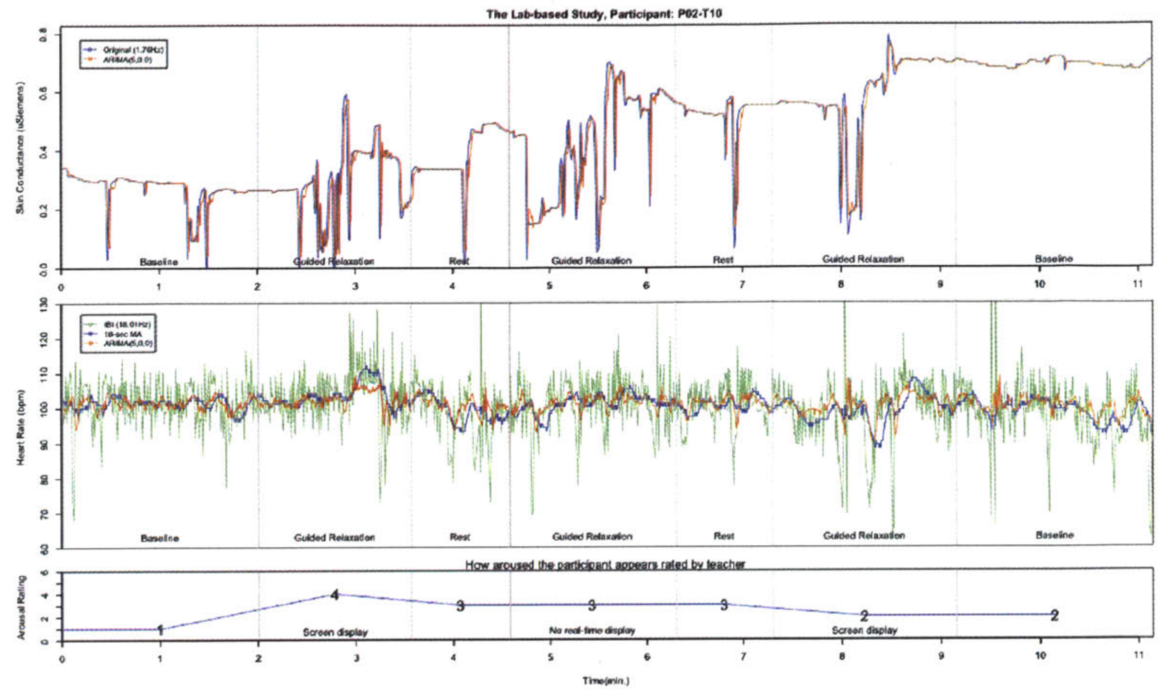
*p<.05

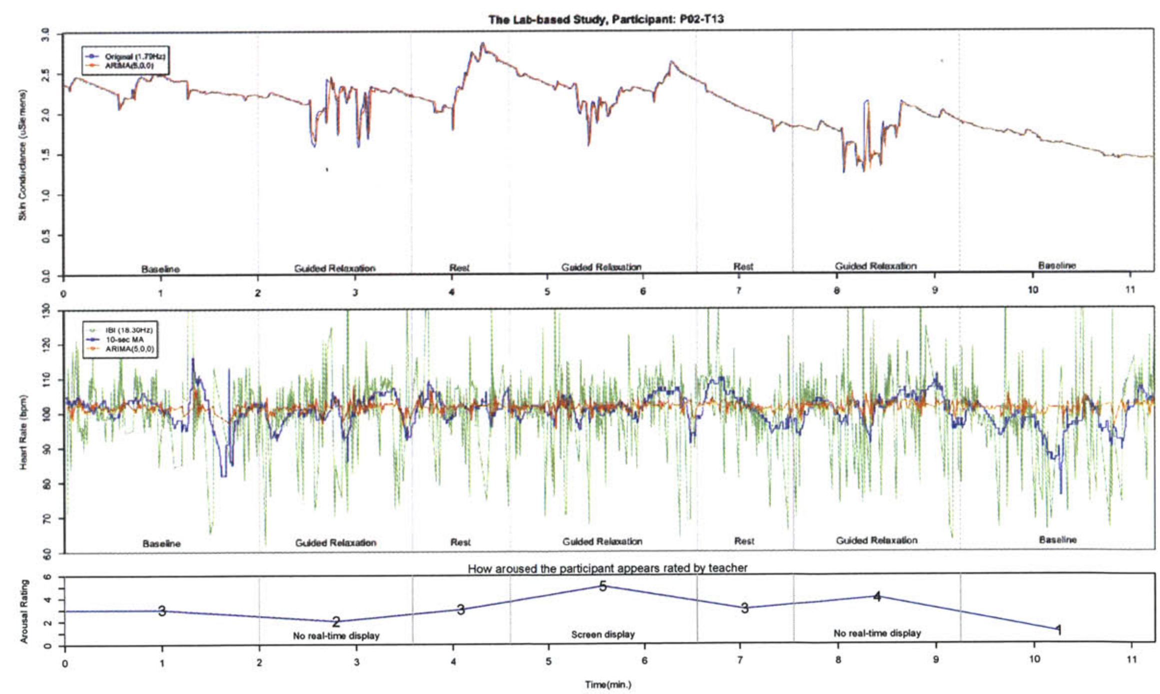
Participant P02
T02, T05, T08, T10, T13, and T14 trials

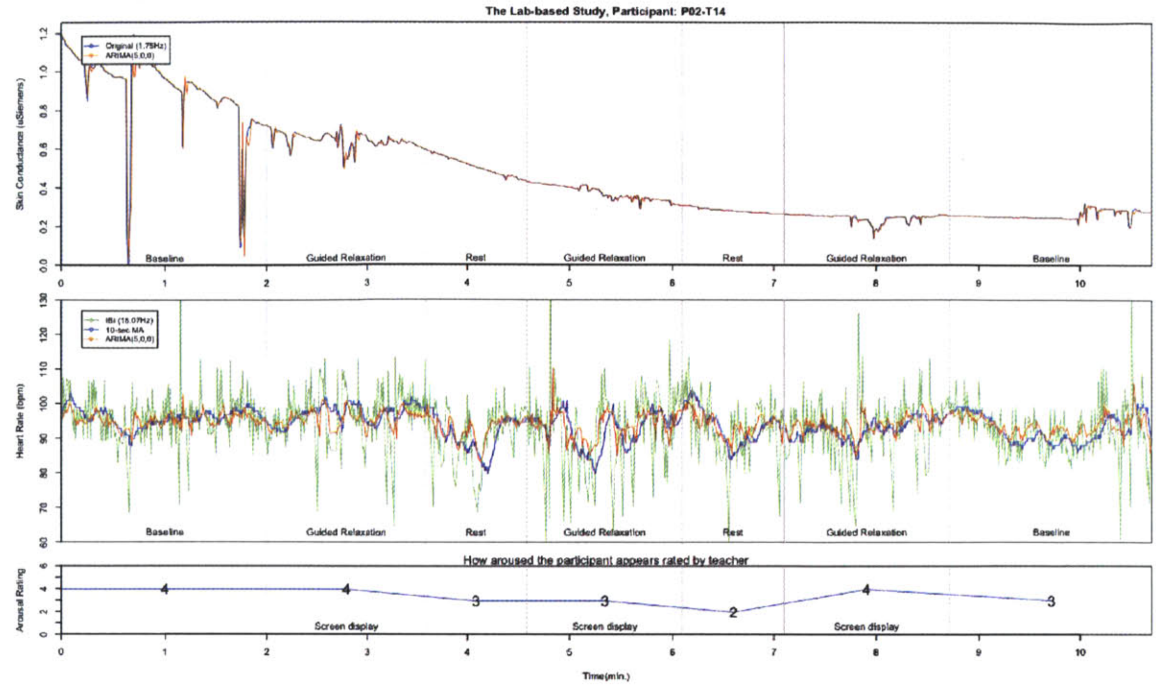



The Lab-based Study, Participant: P02-T05
Skin Conductance (uSiemens)
Heart Rate (bpm)
Arousal Rating
Baseline
Guided Relaxation
Rest
Guided Relaxation
Rest
Guided Relaxation
Baseline
How aroused the participant appears rated by teacher
LED-vibrotactile display
No real-time display
Screen display
Time(min.)

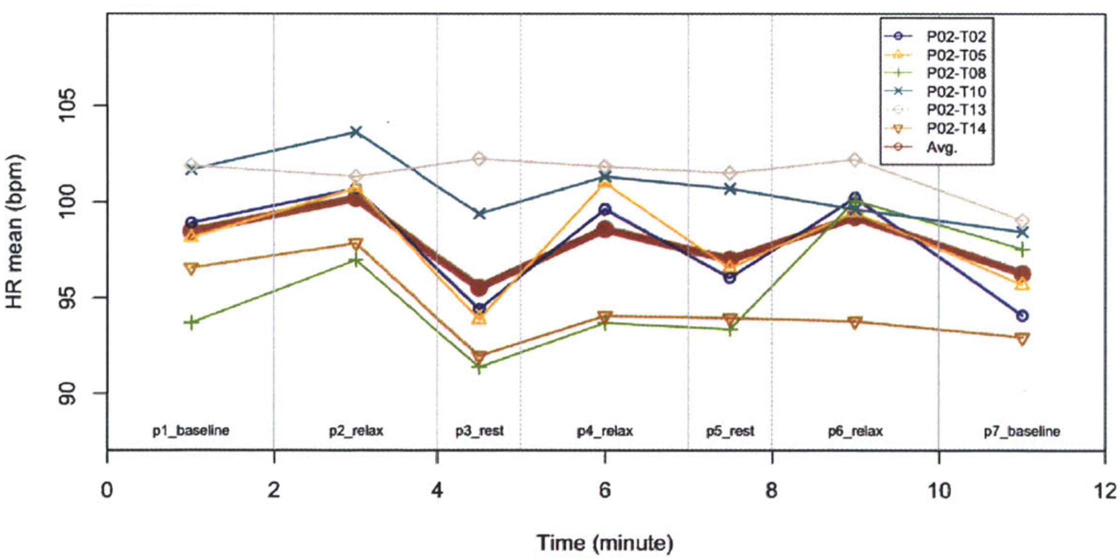

The Lab-based Study, Participant: P02-T06
Skin Conductance (uSiemens)
Heart Rate (bpm)
Arousal Rating
Baseline
Guided Relaxation
Rest
Guided Relaxation
Rest
Guided Relaxation
Baseline
How aroused the participant appears rated by teacher
Screen display
LED-vibrotactile display
No real-time display
Time(min.)


The Lab-based Study, Participant: P02-T10
Skin Conductance (uSiemens)
Heart Rate (bpm)
Arousal Rating
Baseline
Guided Relaxation
Rest
How aroused the participant appears rated by teacher
Screen display
No real-time display
Time(min.)


The Lab-based Study, Participant: P02-T13
Skin Conductance (uSiemens)
Heart Rate (bpm)
Arousal Rating
Baseline
Guided Relaxation
Rest
How aroused the participant appears rated by teacher
No real-time display
Screen display
Time(min.)



P02 Heart Rate Trend (6 trials)



P02 Heart Rate mean value estimation from ARIMA(5,0,0)

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P02-T02	98.9	100.7	94.4	99.6	96	100.2	94.1
P02-T05	98.2	100.7	93.9	101	96.6	99.5	95.7
P02-T08	93.7	97	91.4	93.7	93.3	100.1	97.5
P02-T10	101.7	103.6	99.4	101.3	100.7	99.6	98.4
P02-T13	101.9	101.3	102.3	101.9	101.5	102.2	99.1
P02-T14	96.6	97.9	92	94.1	94	93.8	92.9
Mean	98.5	100.2	95.5	98.6	97	99.2	96.3
SD	3.1	2.4	4.3	3.7	3.4	2.8	2.5
SEM(n=6)	1.3	1	1.8	1.5	1.4	1.2	1

P02 Heart Rate trend comparison:

A significant increase in HR mean (p<.05) from the phase 1 baseline phases to phase 2 verbally guided relaxation, significant decreases in HR mean (p<.05) comparing phase 1 baseline with phase 3 rest and phase 5 rest, and no significant difference in comparing phase 1 to other phases.

P02 (6 Trials)	p1p2	p1p3	p1p4	p1p5	p1p6	p1p7
Paired T-Test p=	0.025*	0.013*	0.901	0.021*	0.608	0.137
p.adjust(BH)	0.049*	0.049*	0.901	0.049*	0.729	0.205

*p<.05

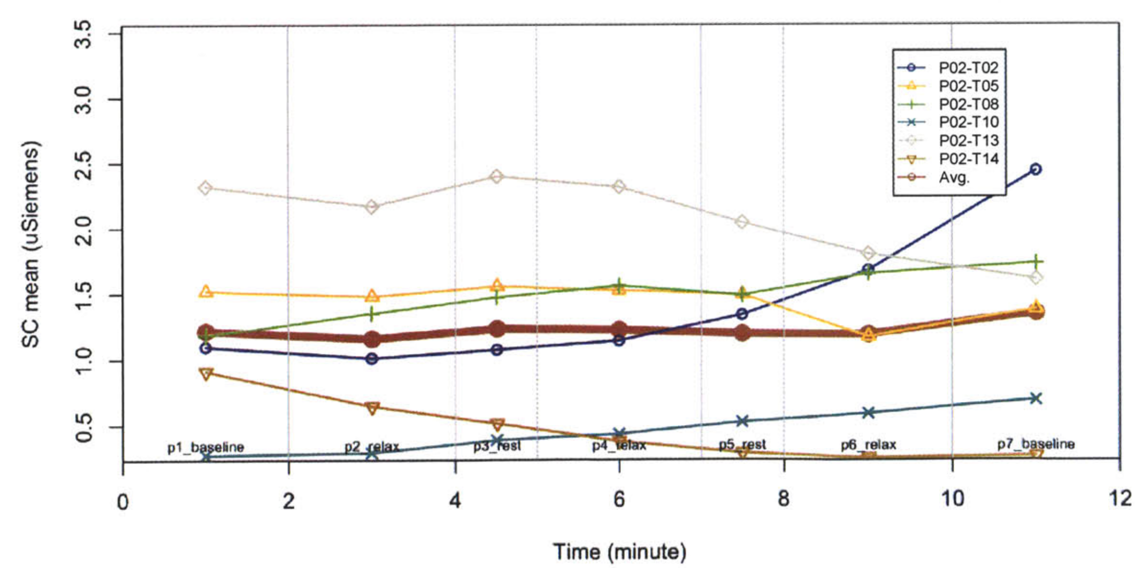
P02 Heart Rate trend comparison:

A significant increase in HR mean (p<.05) from the phase 1 baseline phases to phase 2 verbally guided relaxation, a significant decrease in HR mean (p<.05) comparing phase 2 verbally guided relaxation with phase 3 rest, a significant decrease in HR mean (p<.05) comparing phase 6 verbally guided relaxation with phase 7 baseline, and no significant difference in HR mean comparing other adjacent phases.

P02 (6 Trials)	p1p2	p2p3	p3p4	p4p5	p5p6	p6p7
Paired T-Test p=	0.025*	0.011*	0.039*	0.101	0.126	0.014*
p.adjust(BH)	0.049*	0.041*	0.058	0.121	0.126	0.041*

*p<.05

P02 Skin Conductance Trend (6 trials)



P02 Skin Conductance mean value estimation from ARIMA(5,0,0)

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P02-T02	1.1	1.01	1.07	1.14	1.34	1.68	2.43
P02-T05	1.52	1.48	1.56	1.53	1.5	1.17	1.38
P02-T08	1.18	1.35	1.48	1.56	1.49	1.65	1.73
P02-T10	0.27	0.29	0.38	0.43	0.52	0.59	0.69
P02-T13	2.32	2.17	2.4	2.31	2.04	1.8	1.61
P02-T14	0.91	0.64	0.51	0.37	0.28	0.25	0.26
Mean	1.22	1.16	1.23	1.22	1.2	1.19	1.35
SD	0.68	0.66	0.75	0.74	0.66	0.65	0.78
SEM(n=6)	0.28	0.27	0.3	0.3	0.27	0.26	0.32

P02 Skin Conductance trend comparison:
No significance was found when comparing phase 1 baseline with other phases.

P02 (6 Trials)	p1p2	p1p3	p1p4	p1p5	p1p6	p1p7
Paired T-Test p=	0.382	0.863	0.944	0.9	0.91	0.689
p.adjust(BH)	0.944	0.944	0.944	0.944	0.944	0.944

*p<.05

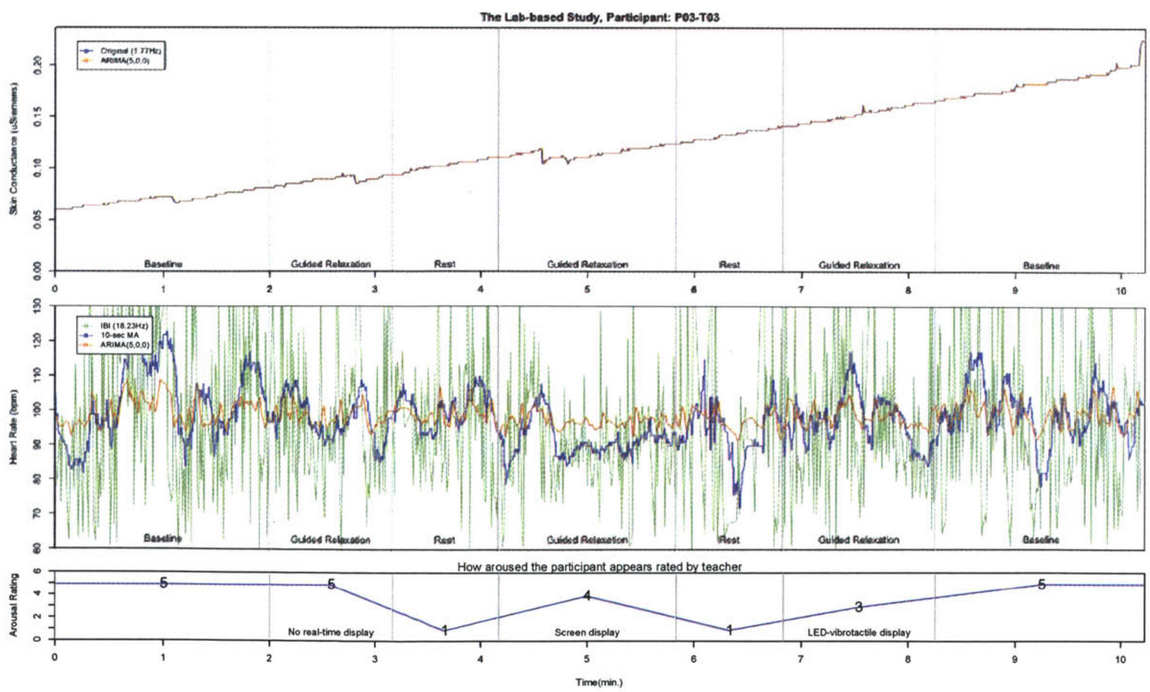
P02 Skin Conductance trend comparison:
No significance was found when comparing every adjacent phase.

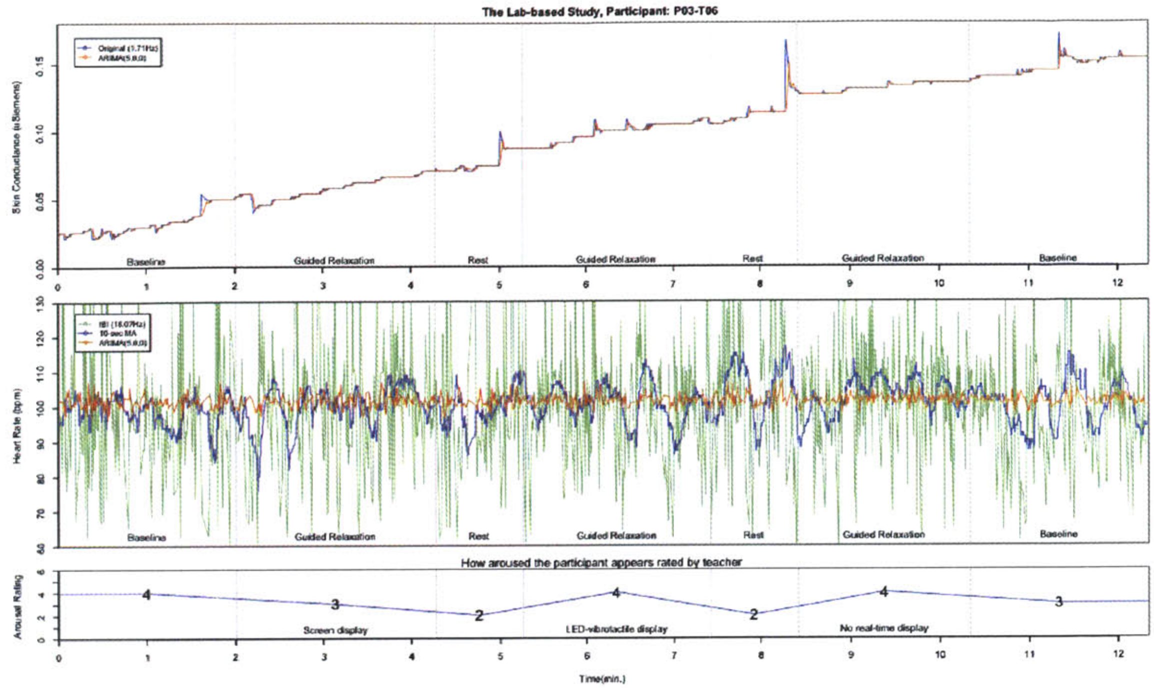
P02 (6 Trials)	p1p2	p2p3	p3p4	p4p5	p5p6	p6p7
Paired T-Test p=	0.382	0.179	0.839	0.678	0.95	0.269
p.adjust(BH)	0.765	0.765	0.95	0.95	0.95	0.765

*p<.05

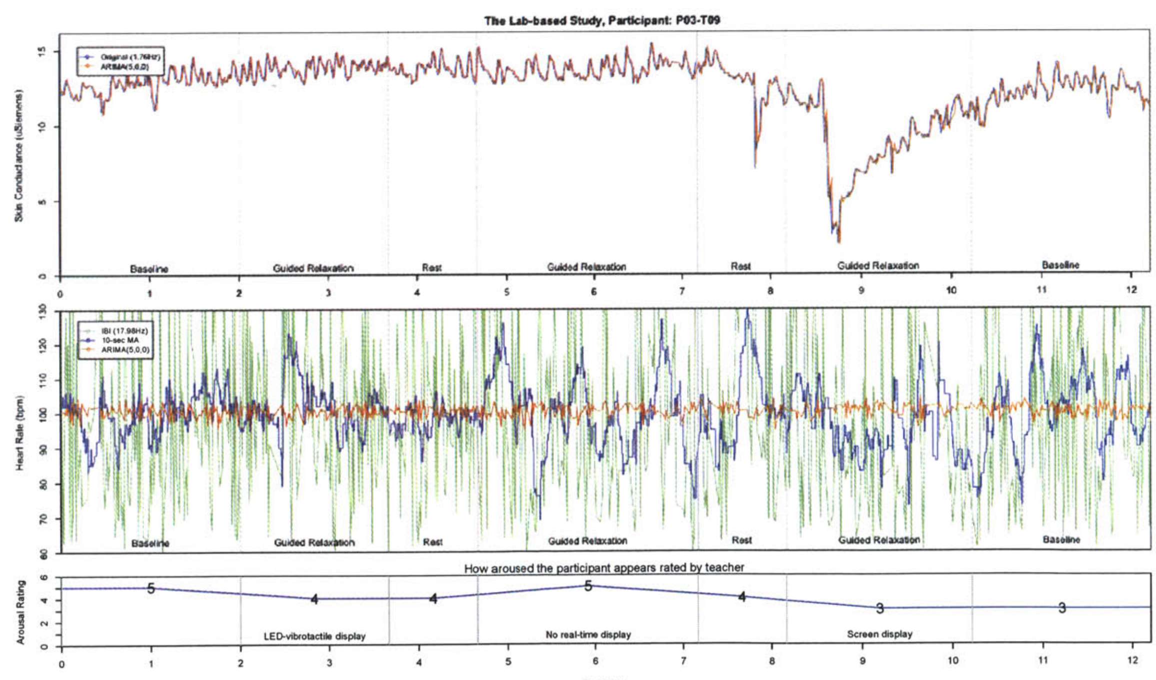
Participant P03

T03, T06, and T09 trials



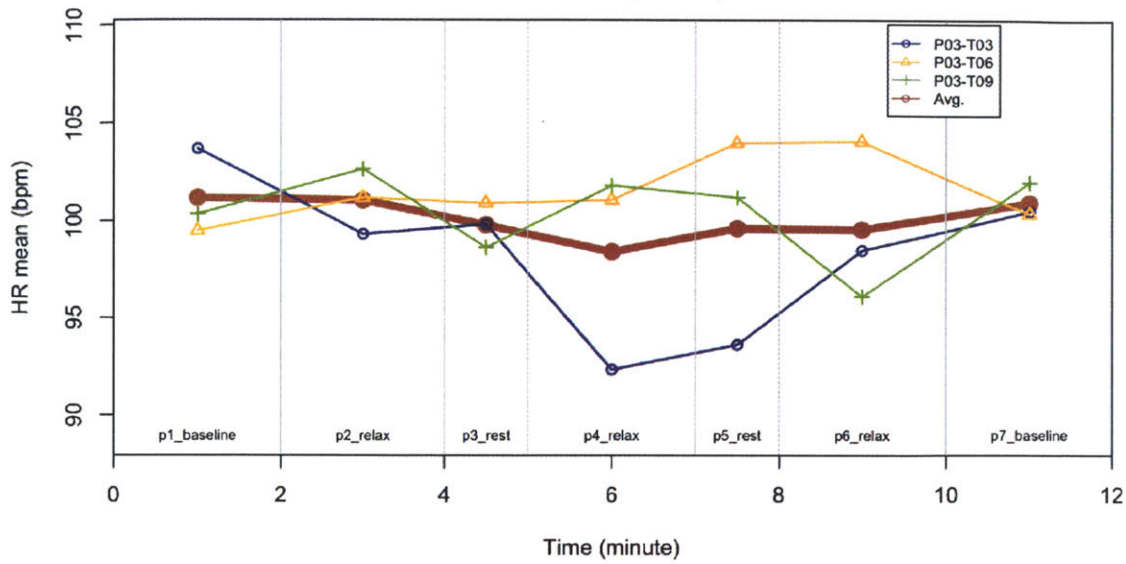


The Lab-based Study, Participant: P03-T06
Baseline
Guided Relaxation
Rest
Guided Relaxation
Rest
Guided Relaxation
Baseline
How aroused the participant appears rated by teacher
Screen display
LED-vibrotactile display
No real-time display
Time(min.)



The Lab-based Study, Participant: P03-T09
Baseline
Guided Relaxation
Rest
Guided Relaxation
Rest
Guided Relaxation
Baseline
How aroused the participant appears rated by teacher
LED-vibrotactile display
No real-time display
Screen display
Time(min.)

P03 Heart Rate Trend (3 trials)



P03 Heart Rate mean value estimation from ARIMA(5,0,0)

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P03-T03	103.7	99.3	99.8	92.3	93.6	98.4	100.4
P03-T06	99.5	101.1	100.9	101	104	104	100.3
P03-T09	100.3	102.6	98.6	101.8	101.2	96.1	101.9
Mean	101.2	101	99.7	98.4	99.6	99.5	100.9
SD	2.2	1.7	1.1	5.2	5.4	4.1	0.9
SEM(n=3)	1.3	1	0.7	3	3.1	2.4	0.5

P03 Heart Rate trend comparison:
No significance was found when comparing phase 1 baseline with other phases.

P03 (3 Trials)	p1p2	p1p3	p1p4	p1p5	p1p6	p1p7
Paired T-Test p=	0.946	0.448	0.581	0.751	0.649	0.873
p.adjust(BH)	0.946	0.946	0.946	0.946	0.946	0.946

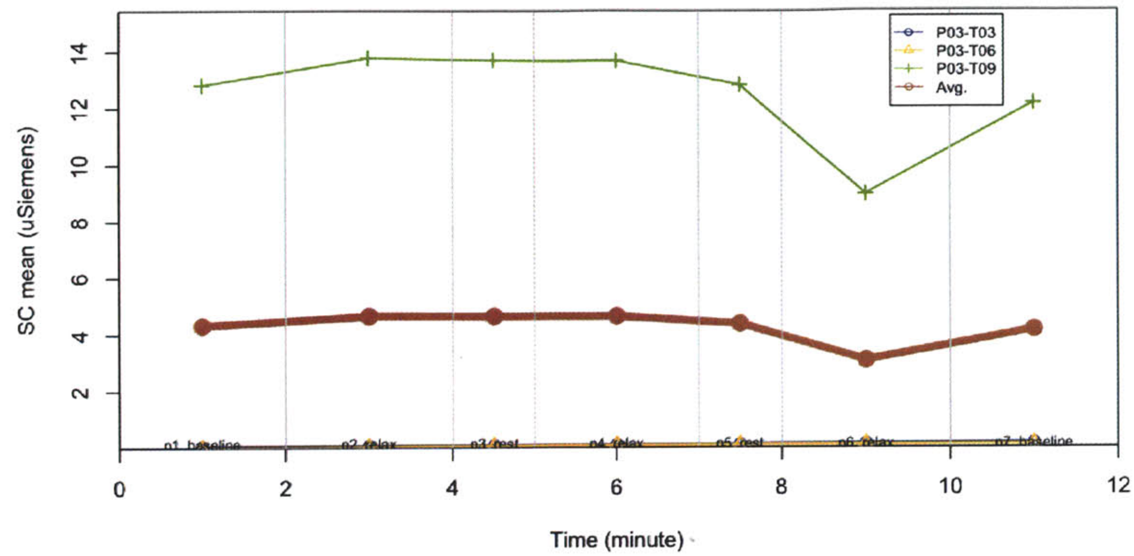
*p<.05

P03 Heart Rate trend comparison:
No significance was found when comparing every adjacent phase.

P03 (3 Trials)	p1p2	p2p3	p3p4	p4p5	p5p6	p6p7
Paired T-Test p=	0.946	0.459	0.71	0.363	0.984	0.669
p.adjust(BH)	0.984	0.984	0.984	0.984	0.984	0.984

*p<.05

P03 Skin Conductance Trend (3 trials)



P03 Skin Conductance mean value estimation from ARIMA(5,0,0)

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P03-T03	0.07	0.09	0.1	0.12	0.13	0.15	0.18
P03-T06	0.03	0.06	0.08	0.1	0.11	0.13	0.15
P03-T09	12.83	13.78	13.71	13.68	12.84	8.95	12.15
Mean	4.31	4.64	4.63	4.63	4.36	3.08	4.16
SD	7.38	7.92	7.86	7.84	7.34	5.08	6.92
SEM(n=3)	4.26	4.57	4.54	4.52	4.24	2.93	4

P03 Skin Conductance trend comparison:
No significance was found when comparing phase 1 baseline with other phases.

P03 (3 Trials)	**p1p2**	**p1p3**	**p1p4**	**p1p5**	**p1p6**	**p1p7**
Paired T-Test p=	0.396	0.373	0.35	0.124	0.45	0.628
p.adjust(BH)	0.54	0.54	0.54	0.54	0.54	0.628

*p<.05

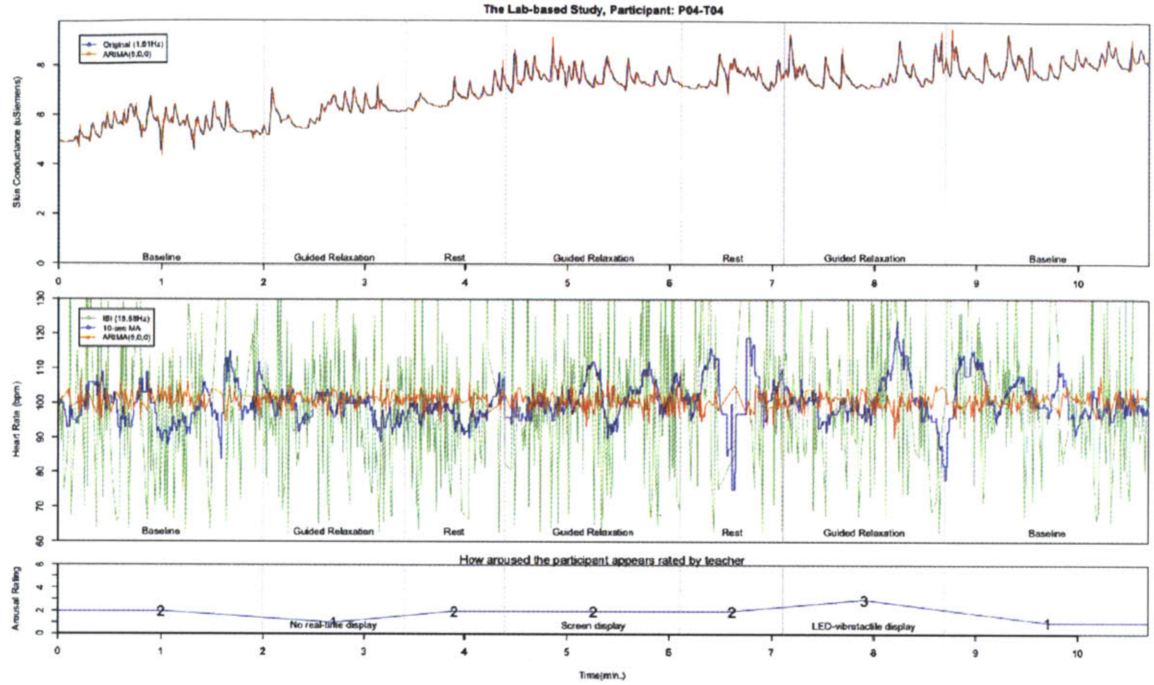
P03 Skin Conductance trend comparison:
No significance was found when comparing every adjacent phase.

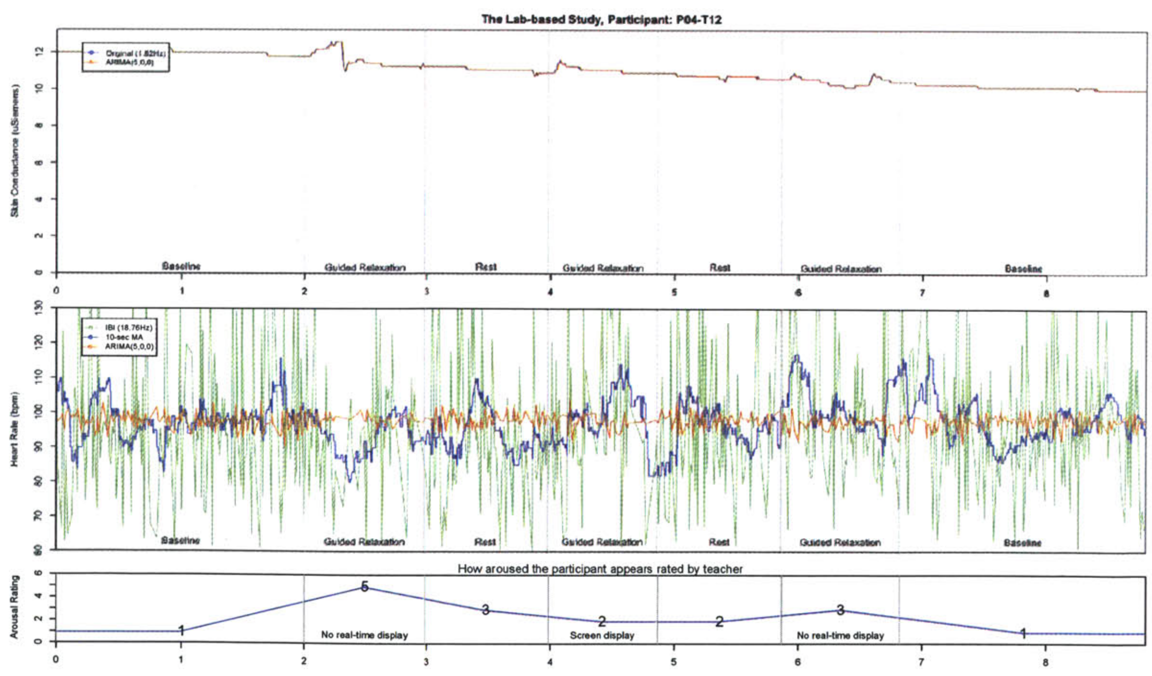
P03 (3 Trials)	**p1p2**	**p2p3**	**p3p4**	**p4p5**	**p5p6**	**p6p7**
Paired T-Test p=	0.396	0.681	0.884	0.445	0.428	0.415
p.adjust(BH)	0.668	0.817	0.884	0.668	0.668	0.668

*p<.05

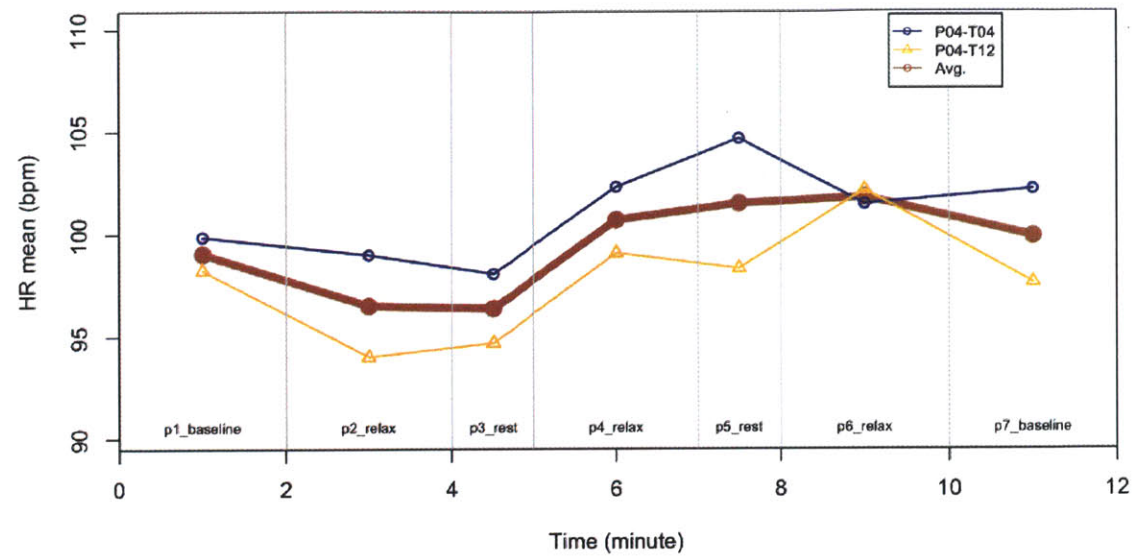
Participant P04

T04 and T12 trials





P04 Heart Rate Trend (2 trials)



P04 Heart Rate mean value estimation from ARIMA(5,0,0)

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P04-T04	99.8	99	98	102.3	104.7	101.4	102.1
P04-T12	98.2	94	94.6	99	98.3	102.1	97.6
Mean	99	96.5	96.3	100.7	101.5	101.7	99.9
SD	1.2	3.5	2.4	2.3	4.5	0.5	3.2
SEM(n=2)	0.8	2.5	1.7	1.6	3.2	0.3	2.3

P04 Heart Rate trend comparison:
No significance was found when comparing phase 1 baseline with other phases.

P04 (2 Trials)	p1p2	p1p3	p1p4	p1p5	p1p6	p1p7
Paired T-Test p=	0.371	0.201	0.287	0.488	0.257	0.663
p.adjust(BH)	0.556	0.556	0.556	0.586	0.556	0.663

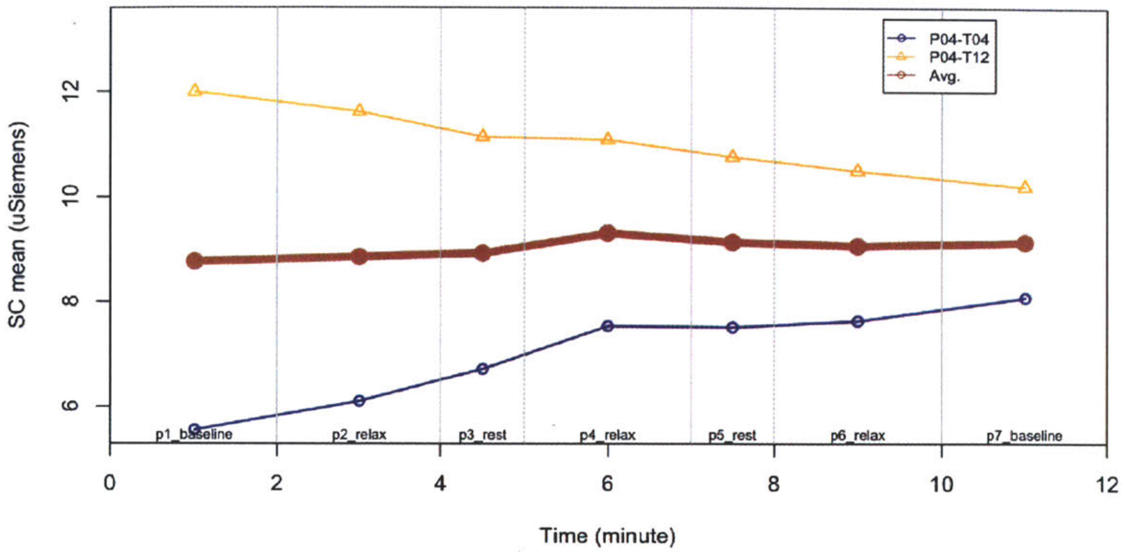
*p<.05

P04 Heart Rate trend comparison:
No significance was found when comparing every adjacent phase.

P04 (2 Trials)	p1p2	p2p3	p3p4	p4p5	p5p6	p6p7
Paired T-Test p=	0.371	0.9	0.011*	0.698	0.951	0.603
p.adjust(BH)	0.951	0.951	0.066	0.951	0.951	0.951

*p<.05

P04 Skin Conductance Trend (2 trials)



P04 Skin Conductance mean value estimation from ARIMA(5,0,0)

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P04-T04	5.56	6.11	6.73	7.54	7.52	7.63	8.07
P04-T12	11.99	11.61	11.13	11.09	10.76	10.5	10.2
Mean	8.78	8.86	8.93	9.31	9.14	9.06	9.13
SD	4.55	3.89	3.12	2.5	2.29	2.03	1.5
SEM(n=2)	3.21	2.75	2.2	1.77	1.62	1.44	1.06

P04 Skin Conductance trend comparison:
No significance was found when comparing phase 1 baseline with other phases.

P04 (2 Trials)	**p1p2**	**p1p3**	**p1p4**	**p1p5**	**p1p6**	**p1p7**
Paired T-Test p=	0.886	0.905	0.774	0.858	0.898	0.896
p.adjust(BH)	0.905	0.905	0.905	0.905	0.905	0.905

*p<.05

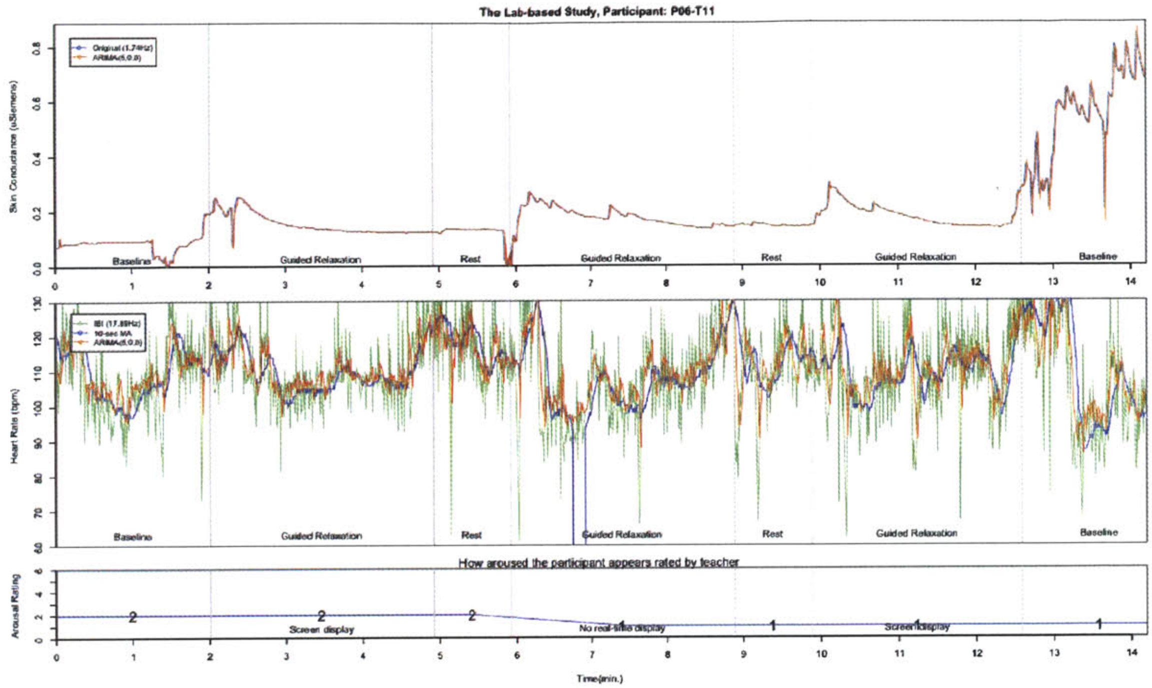
P04 Skin Conductance trend comparison:
No significance was found when comparing every adjacent phase.

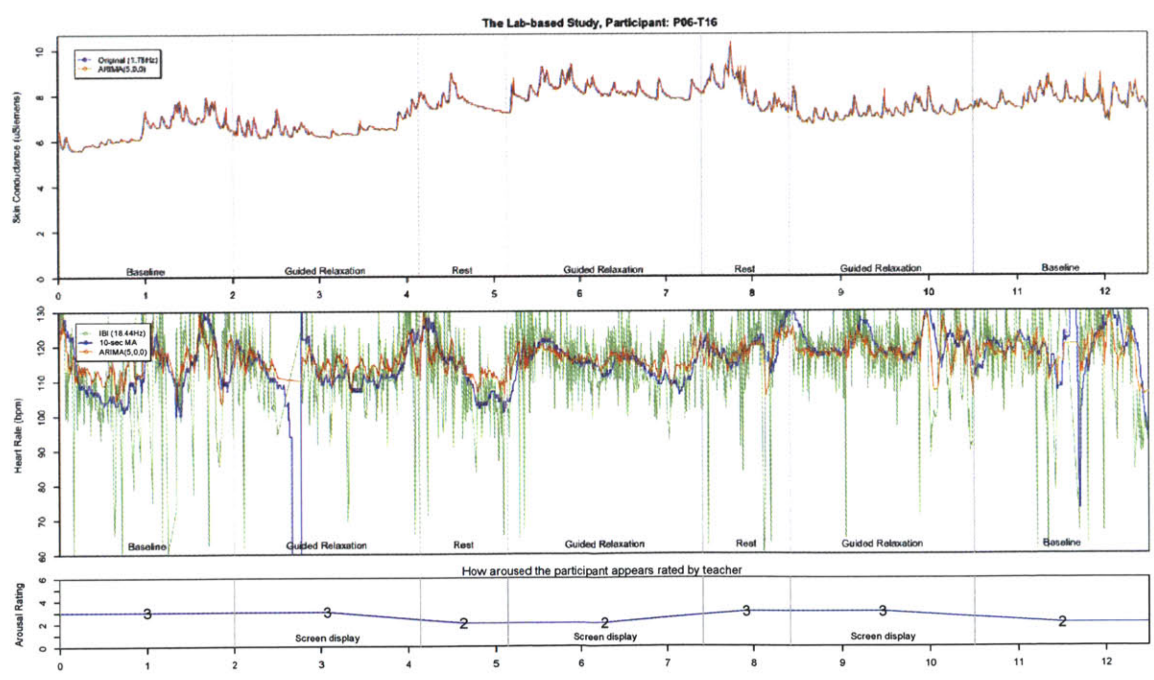
P04 (2 Trials)	**p1p2**	**p2p3**	**p3p4**	**p4p5**	**p5p6**	**p6p7**
Paired T-Test p=	0.886	0.921	0.538	0.452	0.758	0.886
p.adjust(BH)	0.921	0.921	0.921	0.921	0.921	0.921

*p<.05

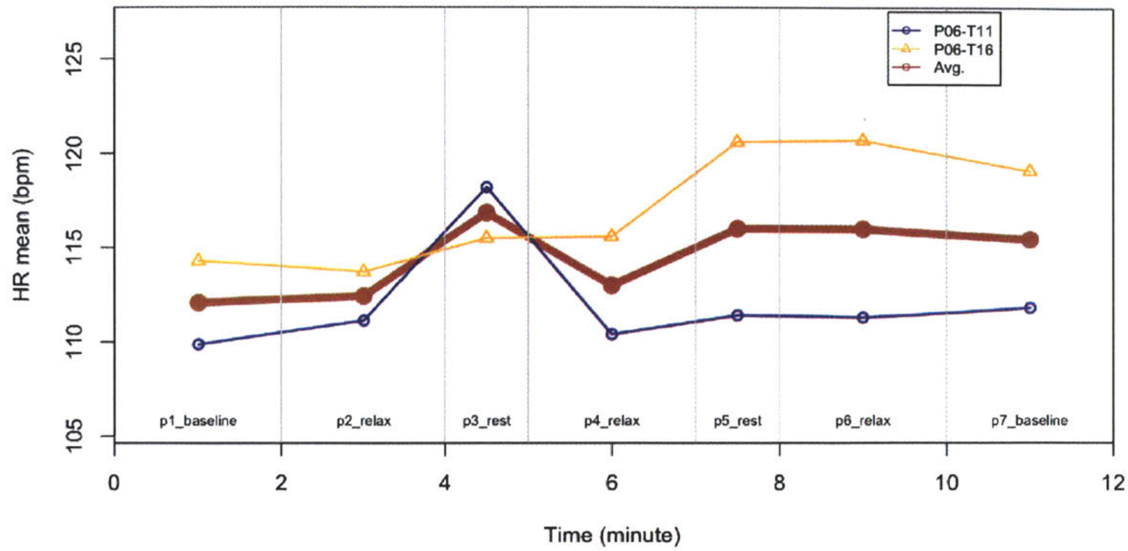
Participant P06

T11 and T16 trials





P06 Heart Rate Trend (2 trials)



P06 Heart Rate mean value estimation from ARIMA(5,0,0)

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P06-T11	109.9	111.1	118.2	110.4	111.4	111.3	111.8
P06-T16	114.3	113.7	115.5	115.6	120.6	120.7	119.1
Mean	112.1	112.4	116.8	113	116	116	115.4
SD	3.1	1.8	1.9	3.7	6.5	6.7	5.2
SEM(n=2)	2.2	1.3	1.3	2.6	4.6	4.7	3.6

P06 Heart Rate trend comparison:
No significance was found when comparing phase 1 baseline with other phases.

P06 (2 Trials)	p1p2	p1p3	p1p4	p1p5	p1p6	p1p7
Paired T-Test p=	0.778	0.409	0.256	0.349	0.364	0.258
p.adjust(BH)	0.778	0.491	0.491	0.491	0.491	0.491

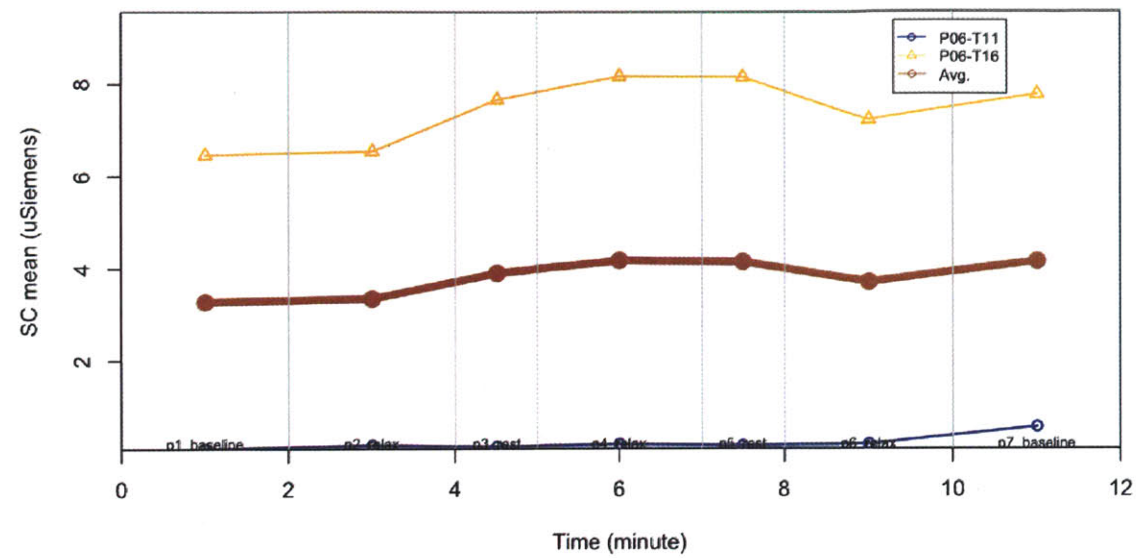
*p<.05

P06 Heart Rate trend comparison:
No significance was found when comparing every adjacent phase.

P06 (2 Trials)	p1p2	p2p3	p3p4	p4p5	p5p6	p6p7
Paired T-Test p=	0.778	0.343	0.507	0.374	0.871	0.698
p.adjust(BH)	0.871	0.871	0.871	0.871	0.871	0.871

*p<.05

P06 Skin Conductance Trend (2 trials)



P06 Skin Conductance mean value estimation from ARIMA(5,0,0)

	p1_baseline	p2_relax	p3_rest	p4_relax	p5_rest	p6_relax	p7_baseline
P06-T11	0.08	0.15	0.12	0.17	0.14	0.18	0.55
P06-T16	6.45	6.53	7.65	8.16	8.14	7.2	7.75
Mean	3.27	3.34	3.89	4.16	4.14	3.69	4.15
SD	4.5	4.51	5.33	5.64	5.65	4.97	5.09
SEM(n=2)	3.18	3.19	3.77	3.99	4	3.51	3.6

P06 Skin Conductance trend comparison:
No significance was found when comparing phase 1 baseline with other phases.

P06 (2 Trials)	**p1p2**	**p1p3**	**p1p4**	**p1p5**	**p1p6**	**p1p7**
Paired T-Test p=	0.034*	0.481	0.467	0.477	0.42	0.282
p.adjust(BH)	0.202	0.481	0.481	0.481	0.481	0.481

*p<.05

P06 Skin Conductance trend comparison:
No significance was found when comparing every adjacent phase.

P06 (2 Trials)	**p1p2**	**p2p3**	**p3p4**	**p4p5**	**p5p6**	**p6p7**
Paired T-Test p=	0.034*	0.518	0.432	0.119	0.524	0.123
p.adjust(BH)	0.202	0.524	0.524	0.246	0.524	0.246

*p<.05

Appendix C.

The lab-based Study arousal trend agreement

HR and SC agreement rate table

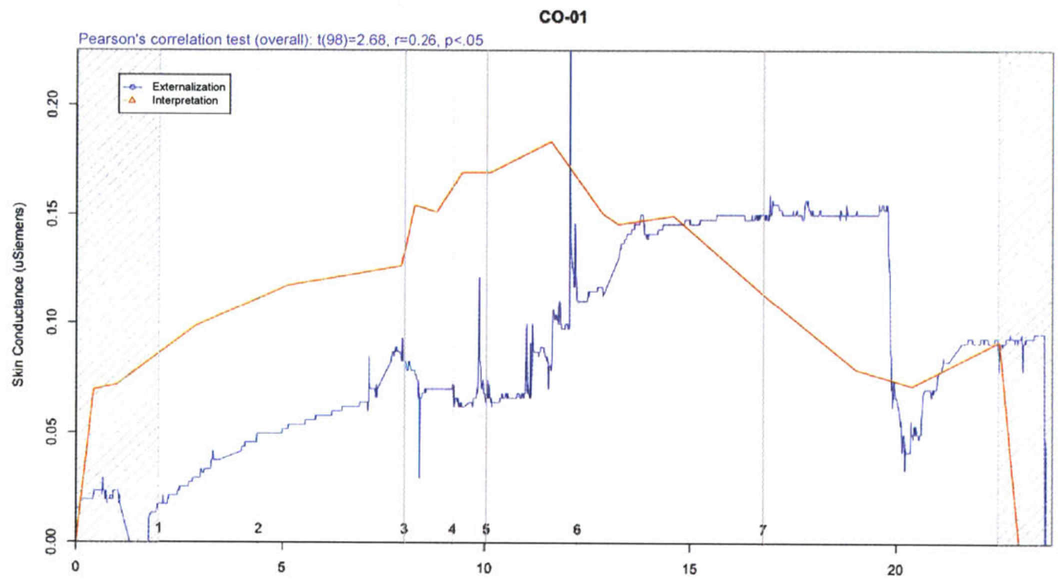
Arousal Trend calculation / Intervention type	Change in HR over full interval		Change in HR over last 50%	
	Mean	De-trended t-test	Mean	De-trended t-test
No Display	58%	40%	55%	50%
Physioboard	77%	70%	73%	65%
MiniHeart	46%	44%	77%	71%
Overall	65%	56%	68%	61%

Arousal Trend calculation / Intervention type	Change in SC over full interval		Change in SC over last 50%	
	Mean	De-trended t-test	Mean	De-trended t-test
No Display	53%	27%	33%	33%
Physioboard	42%	35%	29%	25%
MiniHeart	41%	22%	50%	44%
Overall	45%	31%	34%	31%

Appendix D.

The school-based Study data plots

Participant CO
Trial 01



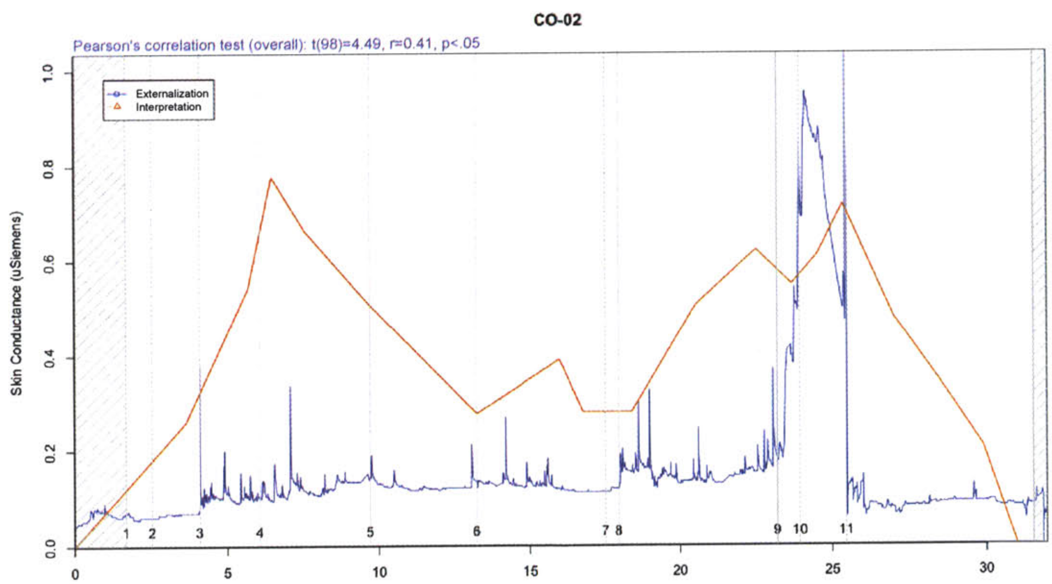
Participant CO's Trial 01. CO's SC data is plotted as blue line. The OT's estimation of CO's arousal is plotted as red line. Pearson's correlation test shows t(98)=2.68, r=.26, p<.05. The CO's SC data and the OT's estimation is positively correlated (r=.26, p<.05).

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
1	1m59s (146s)	OT discussed with CO on their agenda for this session.	Static	M=.03 SD=.01 Slope=.01 SCR/m=0	/
2	4m25s (216s)	OT started brushing CO's arms and feet.	Sensory	M=.06 SD=.01 Slope=.01 SCR/m=.55	M: increase S: n.s. P: increase
3	8m1s (73s)	CO sat on balancing swing.	Vestibular	M=.07 SD=.01 Slope=-.01 SCR/m=0	M: n.s. S: decrease P: decrease
4	9m14s (49s)	CO left the swing.	/	M=.07 SD=.01 Slope=.01 SCR/m=.9	M: n.s. S: increase P: increase

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
5	10m3s (133s)	CO started jumping on the trampoline and passing ball with OT.	Vestibular	M=.08 SD=.02 Slope=.03 SCR/m=3.1	M: n.s. S: increase P: increase
6	12m16s (271s)	OT and CO sat at a desk and OT started using the computer.	Computer	M=.14 SD=.01 Slope=.01 SCR/m=0	M: increase S: decrease P: decrease
7	16m47s (342s)	OT wrote down some texts and CO was asked to type in the text.	Computer	M=.12 SD=.04 Slope=-.02 SCR/m=0	M: decrease S: decrease P: n.s.

Participant CO

Trial 02

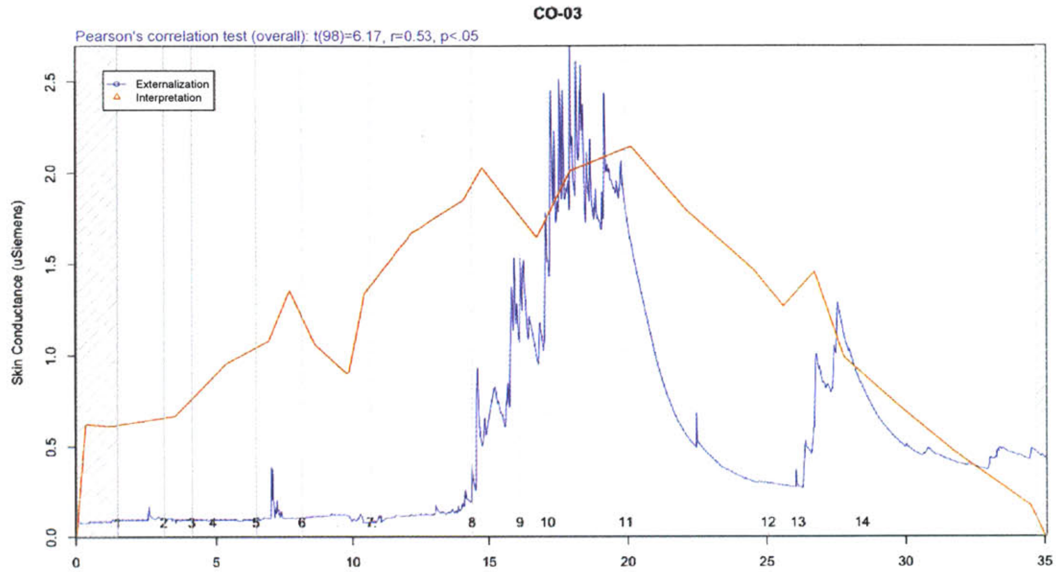


Participant CO's Trial 02. CO's SC data is plotted as blue line. The OT's estimation of CO's arousal is plotted as red line. Pearson's correlation test shows t(98)=4.49, r=.41, p<.05. The CO's SC data and the OT's estimation is correlated (r=.41, p<.05).

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
1	1m40s (51s)	OT discussed with CO about the agenda for this session. OT used PDA with CO.	Static	M=.06 SD=.00 Slope=.00 SCR/m=0	/
2	2m31s (94s)	OT set up the trampoline.	/	M=.06 SD=.00 Slope=.00 SCR/m=0	M: n.s. S: n.s. P: n.s.
@3	4m5s (119s)	CO jumped and passed ball with the OT.	Vestibular	M=.11 SD=.02 Slope=.00 SCR/m=1	M: increase S: n.s. P: increase
@4	6m4s (218s)	CO laid on a roller.	Vestibular	M=.12 SD=.02 Slope=.01 SCR/m=.60	M: increase S: increase P: decrease
5	9m42s (210s)	OT and CO used PDA together.	Static	M=.12 SD=.01 Slope=-.00 SCR/m=.3	M: n.s. S: decrease P: decrease
6	13m12s (258s)	CO walked around.	/	M=.12 SD=.01 Slope=-.01 SCR/m=1.1	M: n.s. S: decrease P: increase
@7	17m30s (27s)	OT set up swing.	/	M=.12 SD=.00 Slope=.02 SCR/m=0	M: n.s. S: n.s. P: decrease
@8	17m57s (316s)	CO sat on the swing.	Vestibular	M=.15 SD=.02 Slope=.00 SCR/m=2.1	M: increase S: n.s. P: increase
@9	23m13s (44s)	OT and CO went to computer room.	/	M=.38 SD=.18 Slope=.7 SCR/m=3	M: increase S: increase P: increase
@10	23m57s (90s)	OT and CO waited the computer program to launch. (Pressing BIS)	Static	M=.74 SD=.14 Slope=-.25 SCR/m=.6	M: increase S: decrease P decrease
@11	25m27s (366s)	CO started typing.	Computer	M=.09 SD=.05 Slope=-.00 SCR/m=.2	M: decrease S: increase P: decrease

Participant CO

Trial 03



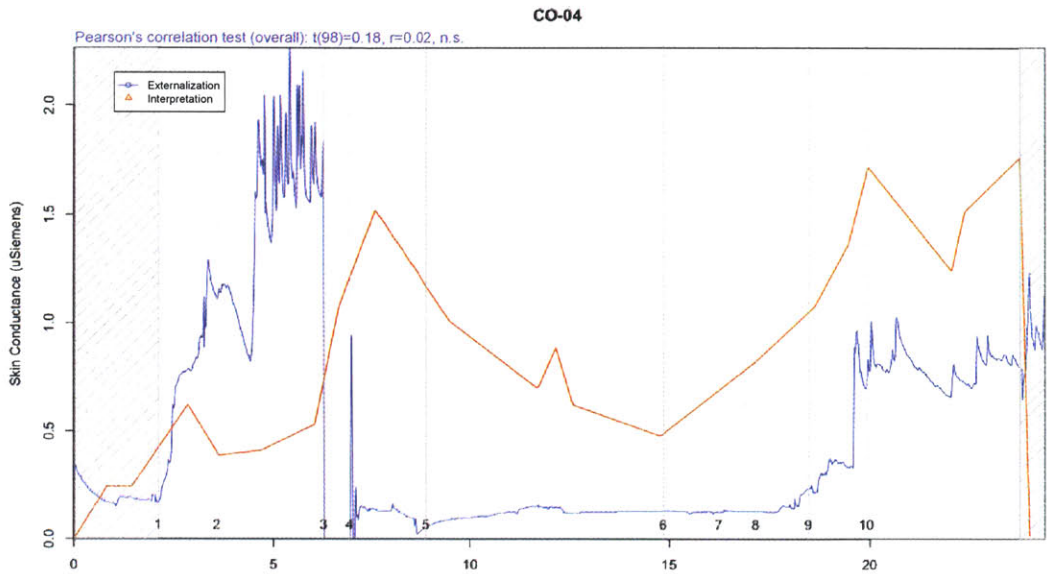
Participant CO's Trial 03. CO's SC data is plotted as blue line. The OT's estimation of CO's arousal is plotted as red line. Pearson's correlation test shows t(98)=6.17, r=.53, p<.05. The CO's SC data and the OT's estimation is correlated (r=.53, p<.05).

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
1	1m28s (99s)	OT brushed CO''s feet.	Sensory	M=.10 SD=.01 Slope=.01 SCR/m=0	/
2	3m7s (60s)	OT started massaging CO''s hands.	Sensory	M=.10 SD=.00 Slope=-.01 SCR/m=0	M: n.s. S: decrease P: n.s.
3	4m7s (46s)	OT started massaging CO''s feet.	Sensory	M=.09 SD=.00 Slope=-.01 SCR/m=0	M: n.s. S: n.s. P: n.s.
@4	4m53s (94s)	OT started massaging CO''s hands.	Sensory	M=.09 SD=.00 Slope=-.00 SCR/m=0	M: n.s. S: n.s. P: n.s.
@5	6m27s (101s)	OT used PDA with CO.	Static	M=.13 SD=.05 Slope=-.03 SCR/m=1	M: n.s. S: decrease P: increase

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
6	8m8s (150s)	OT set up the trampoline and CO wore the weighted sleeves.	/	M=.11 SD=.02 Slope=-.02 SCR/m=0	M: n.s. S: n.s. P: n.s.
7	10m38s (225s)	OT and CO were passing ball.	Vestibular	M=.13 SD=.05 Slope=.03 SCR/m=0	M: n.s. S: increase P: n.s.
@8	14m23s (104s)	OT took off CO"s weighted sleeves and CO sat down.	/	M=.82 SD=.31 Slope=.48 SCR/m=2.91	M: increase S: increase P: increase
@9	16m7s (60s)	OT discussed with CO about the next activity.	Static	M=1.26 SD=.19 Slope=.04 SCR/m=3.98	M: n.s. S: decrease P: increase
@10	17m7s (168s)	OT and CO moved to a desk.	Static	M=1.95 SD=.23 Slope=-.02 SCR/m=4.56	M: increase S: n.s. P: increase
@11	19m55s (308s)	Investigator placed computer on the desk next to CO.	Static	M=.59 SD=.33 Slope=-.21 SCR/m=.2	M: decrease S: decrease P: decrease
@12	25m3s (64s)	OT and CO moved to the computer room.	/	M=.29 SD=.02 Slope=-.0 SCR/m=0	M: decrease S: increase P: decrease
@13	26m7s (139s)	OT booted up the computer and waited for the typing program to launch. (Pressing BIS)	Static	M=.74 SD=.27 Slope=.28 SCR/m=1.29	M: increase S: increase P: increase
@14	28m26s (375s)	CO started using typing program.	Computer	M=.48 SD=.10 Slope=-.04 SCR/m=0.9	M: n.s. S: decrease P: decrease

Participant CO

Trial 04



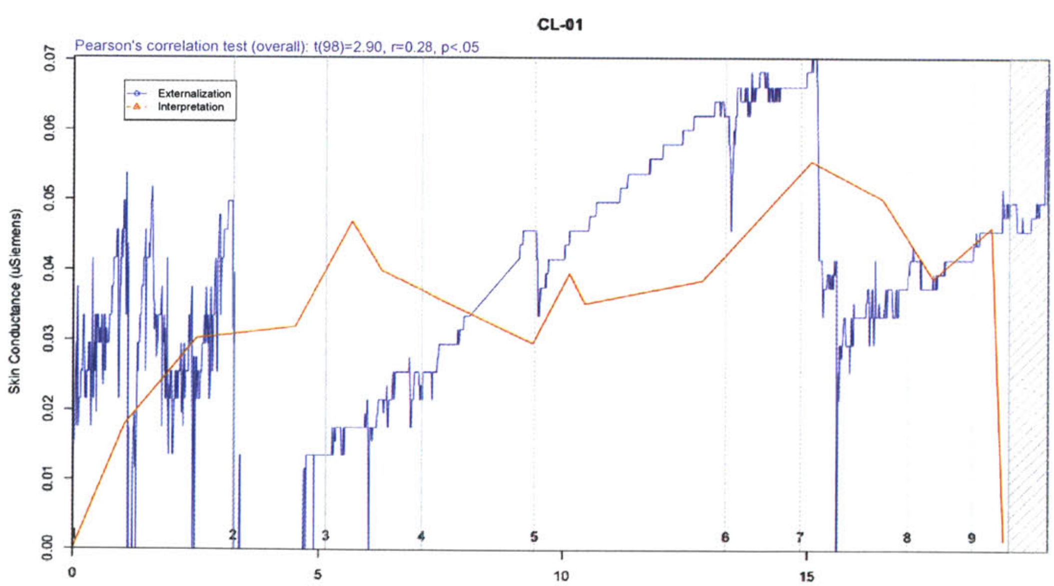
Participant CO's Trial 04. CO's SC data is plotted as blue line. The OT's estimation of CO's arousal is plotted as red line. Pearson's correlation test shows t(98)=.18, r=.02, n.s. The CO's SC data and the OT's estimation is not correlated (r=.02, n.s.).

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
@1	2m5s (88s)	OT and CO started discussing their schedule on the whiteboard. CO was distracted to the window side.	Static	M=.71 SD=.33 Slope=.70 SCR/m=0	/
@2	3m33s (163s)	They both sat on the floor and OT started brushing.	Sensory	M=1.46 SD=.38 Slope=.33 SCR/m=4.4	M: increase S: decrease P: increase
3	6m16s (40s)	OT and CO moved to the computer room and CO took off the wristband.	/	M=.00 SD=.00 Slope=.00 SCR/m=0	/
4	6m56s (117s)	OT helped CO put on the wristband and started the computer program.	Static	M=.12 SD=.12 Slope=-.07 SCR/m=1.03	M: increase S: decrease P: increase
5	8m53s (358s)	Computer program launched and CO started typing.	Computer	M=.12 SD=.02 Slope=.01 SCR/m=0	M: n.s. S: increase P: decrease

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
6	14m51s (83s)	OT paused CO's typing program and moved back to the OT room.	/	M=.12 SD=.00 Slope=-.00 SCR/m=0	M: n.s. S: decrease P: n.s.
7	16m14s (55s)	They sat on the soft surface.	Static	M=.13 SD=.00 Slope=0.00 SCR/m=0	M: n.s. S: n.s. P: n.s.
8	17m9s (79s)	OT put on a headset on CO and CO started listening to an mp3 player.	Auditory	M=.15 SD=.03 Slope=.08 SCR/m=0	M: n.s. S: increase P: n.s.
@9	18m28s (78s)	OT found headset was malfunctioning and asking for an alternative one.	Static	M=.40 SD=.20 Slope=.41 SCR/m=0	M: increase S: increase P: n.s.
@10	19m55s (231s)	Technician passed another headset to OT. OT helped put the new headset on CO and CO listened to the mp3 player.	Static	M=.80 SD=.07 Slope=-.00 SCR/m=.78	M: increase S: decrease P: increase

Participant CL

Trial 01

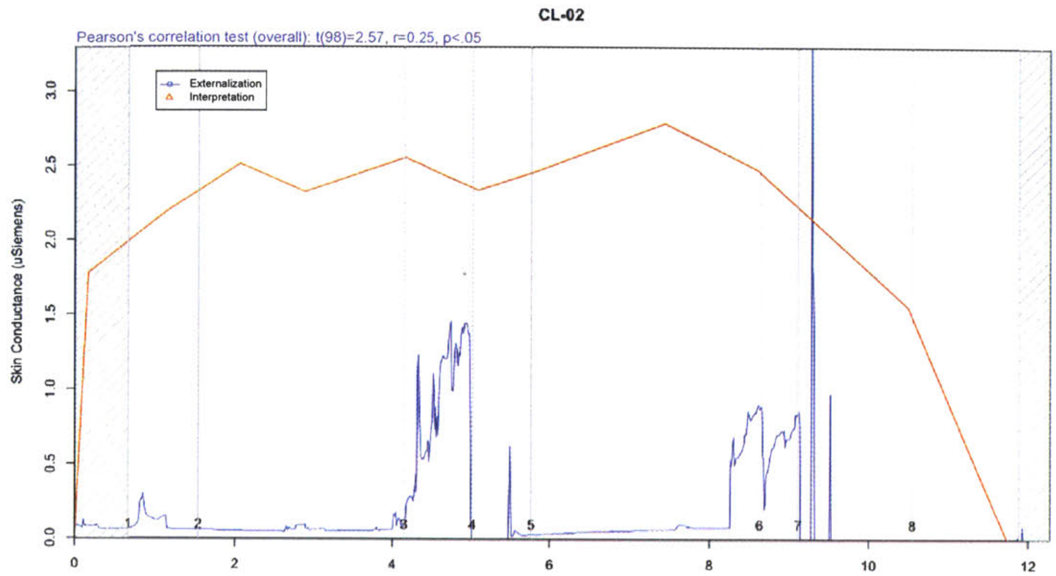


Participant CL's Trial 01. CL's SC data is plotted as blue line. The OT's estimation of CL's arousal is plotted as red line. Pearson's correlation test shows t(98)=2.90, r=.28, p<.05. The CL's SC data and the OT's estimation is correlated (r=.28, p<.05).

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
1	0m1s (193s)	OT and CL were jumping on the	Vestibular	M=.03 SD=.01 Slope=.00 SCR/m=1.3	/
2	3m14s (115s)	trampoline. Investigator adjusted wristband position. OT passed ball to CL.	Static	M=.00 SD=.00 Slope=.00 SCR/m=.0	M: decrease S: n.s. P: decrease
3	5m9s (119s)	CL left trampoline and sat on the therapy ball.	Vestibular	M=.02 SD=.00 Slope=.01 SCR/m=0	M: increase S: increase P: n.s.
@4	7m8s (139s)	OT noticed CL was anxious and OT set up the swing and a sandbox.	/	M=.03 SD=.01 Slope=.01 SCR/m=0	M: n.s. S: n.s. P: n.s.
@5	9m27s (233s)	CL was swinging while putting his feet in sand. Tactile stimulation is usually averse to CL.	Vestibular & Sensory	M=.05 SD=.01 Slope=.01 SCR/m=0	M: n.s. S: n.s. P: n.s.
@6	13m20s (92s)	CL laid inside a swinging net (facing down).	Vestibular & Sensory	M=.06 SD=.00 Slope=.00 SCR/m=0	M: n.s. S: decrease P: n.s.
7	14m52s (130s)	OT asked him to do weight-bearing task. and then to pick up things on the floor while doing linear swing.	Vestibular	M=.04 SD=.01 Slope=-.01 SCR/m=0	M: decrease S: decrease P: n.s.
8	17m2s (79s)	CL left the swinging net.	/	M=.04 SD=.00 Slope=.00 SCR/m=0	M: n.s S: increase P: n.s.
9	18m21s (45s)	CL shows frustrated and shuts off his eyes.	Static	M=.05 SD=.00 Slope=.01 SCR/m=.00	M: increase S: increase P: n.s.

Participant CL

Trial 02

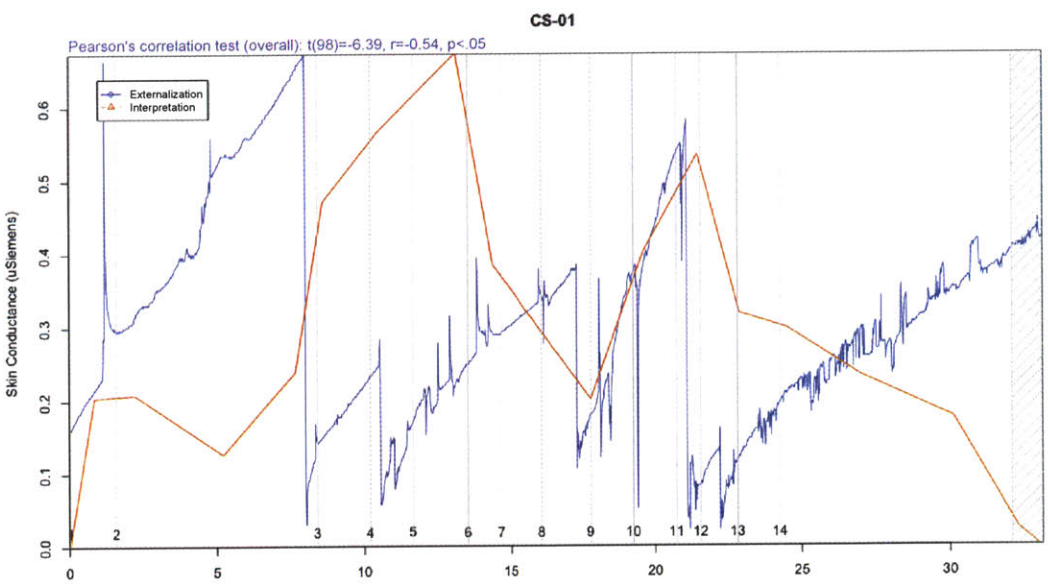


Participant CL's Trial 02. CL's SC data is plotted as blue line. The OT's estimation of CL's arousal is plotted as red line. Pearson's correlation test shows t(98)=2.57, r=.25, p<.05. The CL's SC data and the OT's estimation is correlated (r=.25, p<.05).

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
1	0m40s (52s)	CL watches his favorite YouTube video.	Computer	M=.10 SD=.06 Slope=-.12 SCR/m=1.1	/
@2	1m32s (157s)	OT puts his feet in the rice bin and rubs his feet for calming him.	Computer +Sensory	M=.06 SD=.02 Slope=.01 SCR/m=.30	M: n.s. S: increase P: decrease
@3	4m54s (53s)	CL shows anxious. CL starts rocking. YouTube video ended and CL covers his ears.	Computer +Sensory	M=.83 SD=.43 Slope=1.16 SCR/m=6.85	M: increase S: increase P: increase
4	5m2s	CL takes off the wristband and says all-done. OT puts the wristband back on CL and another teacher sits next to him.	Static	M=.02 SD=.08 Slope=.09 SCR/m=1.1	M: decrease S: decrease P: decrease
5	(44s) 5m46s (172s)	OT massages his feet and chats with CL. OT starts toenail clipping that CL does not like.	Sensory	M=.14 SD=.22 Slope=.17 SCR/m=.32	M: increase S: increase P: decrease

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
6	8m38s (29s)	Sand massage ended.	Static	M=.67 SD=.15 Slope=.47 SCR/m=0	M: increase S: increase P: decrease
7	9m7s	CL took off the wristband.	Static	/	/
8	(86s) 10m33s (80s)	OT put on CL''s socks.	Static	/	/

Participant CS
Trial 01



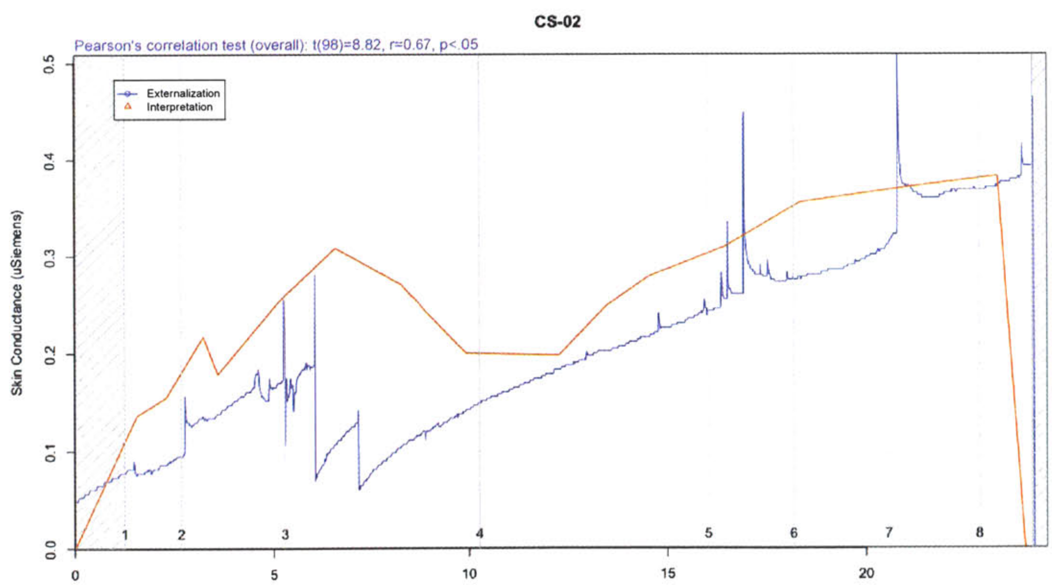
Participant CS's Trial 01. CS's SC data is plotted as blue line. The OT's estimation of CS's arousal is plotted as red line. Pearson's correlation test shows $t(98)=-6.39$, $r=-.54$, $p<.05$. The CS's SC data and the OT's estimation are negatively correlated ($r=-.54$, $p<.05$).

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
1	0m1s (94s)	OT verbally provides the schedule. CS's facial expression shows his high arousal state.	Static	M=.24 SD=.07 Slope=.12 SCR/m=.66	/

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
@2	1m35s (409s)	CS sits on the swing and passes ball with OT. When starting swing, CS's arousal remains the same. Holding could mean he fears the imbalance.	Vestibular	M=.44 SD=.14 Slope=.03 SCR/m=.00	M: increase S: decrease P: decrease
3	8m24s (108s)	OT helps CS stand and walks on the swing. An arousal spike for transition. Standing on a swing is a challenge task.	Vestibular	M=.19 SD=.03 Slope=.05 SCR/m=.00	M: decrease S: increase P: n.s.
4	10m12s (87s)	CS asks to leave the swing and shows frustration. CS wonders around.	Physical	M=.14 SD=.06 Slope=-.05 SCR/=.00	M: decrease S: decrease P: n.s.
@5	11m39s (112s)	CS gets upset, rubs his eyes, and starts crying at the corner. Arousal is high because of the negative emotion and fear.	Static	M=.22 SD=.02 Slope=.03 SCR/m=.94	M: increase S: increase P: increase
@6	13m31s (69s)	CS stands up and goes back to the room. CS is re-engaged in a happier state. Now proceeding to next task.	Physical	M=.29 SD=.02 Slope=.03 SCR/m=1.8	M: increase S: n.s. P: increase
7	14m40s (85s)	OT leads a weight-bearing task. CS lays on the giant ball and grabs objects on the floor.	Vestibular	M=.32 SD=.02 Slope=.04 SCR/m=.70	M: increase S: increase P: decrease
8	16m5s (102s)	Another teacher started talking with CS.	Vestibular	M=.29 SD=.09 Slope=-.13 SCR/m=1.18	M: n.s. S: decrease P: increase
9	17m47s (88s)	CS looks angry and leaves the giant ball. An arousal spike.	Physical	M=.24 SD=.07 Slope=.14 SCR/m=0.67	M: n.s. S: increase P: decrease
10	19m15s (89s)	CS gets upset and goes to the corner and OT sits next to him.	Static	M=.44 SD=.08 Slope=.15 SCR/m=0	M: increase S: increase P: decrease

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
11	20m44s (50s)	OT talks to CS.	Static	M=.30 SD=.23 Slope=-.78 SCR/m=0	M: decrease S: decrease P: n.s.
12	21m34s (77s)	CS cries and OT sat next to him. CS might perceive this is getting to the end of a session and CS does not like transition to another	Static	M=.10 SD=.03 Slope=-.01 SCR/m=2.8	M: decrease S: increase P: increase
13	22m51s (85s)	activity. OT helps CS sit on the swing and OT sits with him.	Vestibular	M=.16 SD=.02 Slope=.05 SCR/m=0	M: increase S: increase P: decrease
14	24m16s (469s)	OT and CS sit at a desk. CS is engaged with desktop tasks. Having eye contact shows he is calm. His body leans towards the OT.	Static	M=.30 SD=.06 Slope=.03 SCR/m=.38	M: increase S: decrease P: increase

Participant CS
Trial 02



Participant CS's Trial 02. CS's SC data is plotted as blue line. The OT's estimation of CS's arousal is plotted as red line. Pearson's correlation test shows t(98)=8.82, r=.67, p<.05. The CS's SC data and the OT's estimation are correlated (r=.67, p<.05).

Phase	Event start (Duration)	Event	Event Type	Mean, SD (uS) Slope (uS/min) SCR/Min	Arousal Trend
1	1m14s (84s)	CS takes off the shoes.	Static	M=.08 SD=.01 Slope=.01 SCR/m=.63	/
2	2m38s (159s)	OT guides a weight-bearing task. CS lies on the giant ball (facing ground) and plays with a toy piano. Music is a prefer activity to CS.	Vestibular	M=.15 SD=.02 Slope=.02 SCR/m=1.6	M: increase S: increase P: increase
3	5m17s (299s)	OT massages CS''s hands. CS shows frustration and tries to walk away. CS sits in the beanbag. OT keeps massaging and performs joint compressions.	Sensory	M=.12 SD=.03 Slope=-.00 SCR/m=.20	M: decrease S: decrease P: decrease
4	10m16s (346s)	OT presses CS''s feet. CS pulls his legs toward the body showing him in a high arousal state.	Sensory	M=.20 SD=.03 Slope=.02 SCR/m=.53	M: increase S: increase P: increase
@5	16m2s (129s)	CS stands up and OT sets up the swing. The swing might be to difficult at this moment.	Physical	M=.27 SD=.02 Slope=.01 SCR/m=2.9	M: increase S: decrease P: increase
6	18m11s (143s)	CS sits on a balancing object.	Vestibular	M=.29 SD=.01 Slope=.01 SCR/m=.00	M: increase S: n.s. P: decrease
7	20m34s (137s)	CS is ready to leave. OT helps CS put on his shoes.	Static	M=.36 SD=.02 Slope=.01 SCR/m=.45	M: increase S: n.s. P: increase
8	22m51s (80s)	OT talked to another teacher.	Static	M=.38 SD=.01 Slope=.02 SCR/m=.65	M: n.s. S: n.s. P: increase