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INWARD TO OUTWARD

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Abstract

This is me, my hair, my lip, my smell, the way my head moves and the body I live in. The sense of self is not fixed but continuously updates in response to the present information. When the body senses itself internally and localizes its actions, it provides the basis for a material sense of self existence. At the same time, the mind registers the sense of an agency with free will, the sense of being, the cause of voluntary action. The present self continuously becomes the past, and by the time we look into it we are in another present, consumed with planning the future.[1] This thesis describes my theory and practice that concerns the sense of self. Two projects, *Being A Tree* and *Masque*, are included as examples of altering the perception of self through multi-sensory stimulation of exteroceptive signals and false feedback of interoceptive signals. Through these two systems, I aim to provide the audience a new, though temporary, relationship with themselves.

This thesis incorporates my technical contribution in human computer interaction as well as my artistic inquiry. The goal is to reconfigure the tools of technology, not for exploitation but for the recovery of human feelings, affects and emotions.

I hope the thesis delivers more than just the systems and study data. This thesis is about the moments of self-(re)organization and creating ripples in the fabric of self. It pays close attention to our shared psychological, emotional, cultural, and perceptual approaches to the inner and outer world and tries to bring light back to the sensitivity of self.

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[1] "*Present continuously becomes past, and by the time we take stock of it we are in another present, consumed with planning the future, which we do on the stepping-stones of the past. The present is never here. We are hopelessly late for consciousness.*" - Antonio Damasio

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INWARD TO OUTWARD

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INWARD TO OUTWARD

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INWARD TO OUTWARD

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Content

1. Introduction

When Alice meets the caterpillar in Wonderland, the caterpillar asks:

"who are you?"
This was not an encouraging opening for a conversation. Alice replied, rather shyly, "I - I hardly know, sir, just at present --- at least I know who I was when I got up this morning, but I think I must have been changed several times since then."
"What do you mean by that?" said the Caterpillar sternly, "Explain yourself!"
"I can't explain myself, I am afraid, sir" said Alice, "because I'm not myself, you see."
"I don't see," said the Caterpillar.
"I'm afraid I can't put it more clearly," Alice replied very politely, "for I can't understand it myself to begin with; and being so many different sizes in a day is very confusing."
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Figure 1.1 Alice in Wonderland, Illustrated by Sir John Tenniel

"Who are you", is a hard question for Alice. After her body turned big and small several times in a day, she found herself uncertain. How could she know that she is still herself, or, is she not? Ultimately, how does one perceive oneself is the question explored in this thesis.

1.1 Self-(re)cognition

It was during an online conversation with an old friend of mine that I noticed the changes in myself after three years of being in a foreign country. We were talking on WeChat through voice messages. She was a bit slow so I got bored and started listening to the previous exchanges, among them recordings of my own voice. Just like everyone else, I am not fond of my own voice. But this time I paid special attention to my sentences as their rhythms appeared quite different than I remembered, as if broken. There were awkward pauses in places that do not make sense in Chinese, and I quickly figured out that they were due to my habits in English wording. For example, words I use in professional settings, like *presentation, brainstorm, lab*… do not get translated into Chinese in my head naturally. Since I find it impolite to mix English words into my Chinese conversations, I often have to pause a bit to search for 报告，头脑风暴，实验室 … These recurrent pauses not only slow down my speaking speed, but also make me sound indecisive. The surprising result is that when I heard myself stumbling, despite knowing why, I thought that I was truly indecisive and hesitating during the conversations. Or rather, the broken sentences fed back to my thoughts and the flow of logic and arguments became chaotic. I started to pay attention to how I talk differently in Chinese and English: I greet people with an enthusiastic tone in English. My sense of humor swings between sassy and funny depending more on the language than the content. I have to raise my voice to get attention while speaking English because I simply cannot enunciate words as clearly and confidently as in my native language. In the end, I noticed two parallel versions of me living together, a Chinese speaking one and an English speaking one.

I wonder how these fine details in my daily activities are shaping who I am? The voice I heard of myself does not only come from the vocal cord resonances along with the formations of my throat and mouth, but also the echo from the environment transmitted to my ear together with the sound through bone conduction. I constantly hear myself transduced back and inevitably turn into being whom I heard.

Similar moments of self-confusion occur from time to time: looking into the mirror after a new haircut and seeing someone unfamiliar, picking up the clothes that won't fit anymore, disliking the taste of a food which used to be my favourite. I can't help but imagine that there are different versions of myself varying along time, and I just have to get to know them/us again and again.

1.2 Inward to Outward

The sense of self grounds the individual in the midst of our kaleidoscopic world. I see my experience apart from other people and believe in my independent personality. However, there are countless moments and events that nevertheless influence my daily choices and the making of my world, like humid weather, a menstrual period and a double shot of espresso. The work of *Inward to Outward* is about these aspects, the incidents that permeate into one's sense of self and obscure individuality without being noticed. By examining and constructing these experiences, I hope to reveal the connection between the self and the outer world, and further bring back the sensitivity and awareness of self.

Inward to Outward looks into the sense of self from its sensory, perceptual perspective. This thesis describes several projects that alter the sense of self through synchronized, multi-sensory feedback on exteroceptive and interoceptive cues that change affective feelings from the body. Through the development of built projects, performances and user studies concerning changes in self-perception, I present the self as it inter-mingles with the external world, both consciously and subconsciously, and manifesting on personal, social and political levels

1.3 Thesis Contribution

This thesis concerns the sense of self from physical experience and specifically how the integration of sensory stimuli forms a cognitive instantiation of subjective experiences.

The contribution of this thesis is twofold. First, my exploration into providing mediated interoceptive/exteroceptive sensations provides a practical and technological framework for creating self-altering perceptual experience. Second, the projects in practice showcase the connection between emotion and body experiences, and their implications in daily use.

In a larger sense, my hope is that: first, this thesis can remind readers of the sensitivity needed for one to be connected to oneself in the society; and second, that the work provides practical guidance to deliver positive body experiences that improve one's self-image and physical wellness.

In addition to the artistic and theoretical contributions, the physical contributions of this thesis work are:

- Design and development of Masque, a psychoacoustic device that manipulates the sound of respiration.
- Design and implementation of two studies that examine the affective aspects of Masque.
- Build and iteration on two multi-sensory virtual reality films TreeSense and Tree, in which the audience is transformed into a tree.

1.4 Thesis Structure

In Chapter 2, I review a list of works and research that focus on the relationship between body experience, physiological condition and the sense of self. In Chapter 3, I discuss the struggle and desire to be oneself in relationship to the body we possess, the society we live in and ideologies that we share. I hope these two chapters form the foundational knowledge of self-perception and its role in our daily biological, personal, social and political lives.

Chapter 4 and 5 present two projects that utilize exteroceptive and interoceptive stimuli, respectively, to alter the perception of self, while the user is consciously or subconsciously aware of the changes. The first project is **Being a Tree** discussed in Chapter 4, which uses multi-sensory stimulation in virtual reality to induce a Body Ownership Illusion. The project expands from a research question to a large-scale deployment as a high-production virtual reality film. The main work of this thesis - **Masque** - is a mask-shaped, psychoacoustic device that manipulates respiration sound, in order to influence bodily-related emotional state. Chapter 5 describes the design, technical architectures and two user studies of Masque.

In the last chapter, 6, I summarize the work and propose future research.

2. Background : Self-(re)cognition and the Lived Body

2.1 Self between the Mind and the Body

"How are you feeling?"

The answer could be either a mental state or a body condition: "I am so excited," "my back hurts" or both: "I am too tired to enjoy the movie." Thinking of ourselves, we examine both our body and mind. It is often the case that a nice morning run boosts up a rather dull day, or being sick can make any party unpleasant. But what is the relationship between body and mind? What is the intermediary between them? Where is the self? These questions have drawn enormous interests from researchers in psychology, cognitive science and neuroscience, as well as philosophers and practitioners in arts and technology. These research works form the basis on how the biological machinery - body - establishes the foundation of our consciousness, self-awareness and subjectivity. When the body senses itself internally and localizes its actions, it provides the basis for a material sense of self existence. At the same time, our mind registers the sense of an agency with free will: the sense of being the cause of voluntary actions. The evolution of body-mind theory spans from Descartes' "Cogito, ergo sum" to Andy Clark's *The Extended Mind*, but here I want to suggest an exercise to the reader first.

2.1.1 Heart

Sit down.
Try to track your heartbeat by tapping on your feet without touching the pulse.
Do this for about 30 seconds.

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Now, keep the rhythm on your feet, but feel your pulse.
Are they synced?
How different are they from each other?

Sensing the heartbeat is an experience that leaps between our body and mind. Except when the heart pounds on the chest after strenuous exercise, it is not easy to count pulses when calm. The sensory perception of the presence and activities of our internal organs, including the heart, lungs and stomach, is summarized as *visceral perception*. Unlike external stimuli, the events inside the body are difficult to be detected explicitly ("Where is the food, my dear stomach?") and often not even necessarily sensible[2] ("How about my blood pressure?"). Right now, your body is actively monitoring and adjusting cardiovascular activity. Each time the heart pumps oxygenated blood to the rest of body, your internal body senses the mechanical (barosensory) and chemical (chemosensory) information of the vessel deformation and the partial pressure of oxygen and carbon dioxide in the blood. This information then affects the parasympathetic and sympathetic activities of your autonomic nervous system, which ultimately modulate our cardiovascular function (Purves, Augustine, & Fitzpatrick, 2001). All these sensing and regulating functions are not sensible in daily life as the majority of human's life-supporting system simply replies on the automatic, unconscious activities developed through evolution.

Though the autonomic nervous system does not keep a count of heartbeats in the conscious mind, a person can perceive their heart contractions on demand like in the exercise above. Is it a procedure that simply takes commands from the mind, and the heart sends signals back for interpretation? Without putting a hand on the chest, how do we actually sense a pulsatile organ inside the body? In *Visceral Perception*, Gyorgy Adam argues that "most people feel their rhythmic heart contractions and pulse intervals through a combination of several senses: real visceral ceptive impulses coming from the sensory nerves of the heart itself mixed with auditive ones coming through the pulses of the middle and inner ear, pulsations of the neck and wrist, skin, and elsewhere. Thus, heartbeat detection is a real form of perception in which several sensations - external and internal - play a given role and expectation." (György, 1998) While doing this, we fully concentrate on the faint sensory signals under the skin and our mind does nothing but count: one, two, three.

Though the cardiac signals are not in the conscious mind all the time, those cardiac signals connect with the other cognitive and sensorial experiences, subconsciously. In a study published in *Journal of Neuroscience,* a series of experiments showed that the rhythm of visual stimuli with respect to the heartbeat modulates visual awareness (Salomon, et al., 2016). When the visual stimulus is synchronized with the heart rate of the observer, the fMRI shows a reduced activation for the stimuli at the insular cortex. This region of the brain is sensitive to visual signals and also associated with self-awareness. "The brain knows that the heartbeat is coming from the self, so it doesn't want to be bothered by the sensory consequences of these signals," says Roy Salomon, one of the study's co-authors in an interview with *Scientific American* (Kwon, 2016).

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[2] In the sense of perceptible by sensory organs.

The ability of sensing one's own heartbeat and its implication go way beyond the biological sensations. In fact, heartbeat detection is now widely used as an indicator for interoceptive sensitivity in cognitive studies (Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015): researchers have documented that "viscerally aware" people are more emotionally expressive (Ferguson & Katkin, 1996) and that those people are able to experience a higher intensity of emotions (Wiens, Mezzacappa, & Katkin, Heart beat detection and the experience of emotion, 2000). The sense of our heartbeat is a gateway to our feelings, emotions and identity.

2.1.2 The sentient self

The concept of interoception was defined with respect to visceral sensations inside the body, such as pain, temperature, hunger and thirst. Now the term is used to include the sense of the physiological condition of the entire body (Craig A. , 2003) and the ability of visceral afferent information[3] to reach awareness and affect behavior (Fowler, 2003). Neuroanatomical research suggests that information concerning the internal state of the body is conveyed through a dedicated structure in the brain: a lamina-1 spinothalamocortical pathway that converges with vagal afferents, connecting 'interoceptive centers' in insular and orbitofrontal cortices (Craig A. D., How do you feel? Interoception: the sense of the physiological condition of the body, 2002). Functional magnetic resonance imaging (fMRI) shows the anterior insular cortex is activated by interoceptive experiences such as autonomic arousals, visceral stimulation (Aziz, Schnitzler, & Enck, 2000), pain (Peyron, et al., 2002) and temperature (Craig, Chen, Bandy, & Reiman, 2000) as well as emotional processing (Büchel, Morris, Dolan, & Friston, 1998). Since the region of brain in charge of painful sensations is also activated by emotions, heartache from sadness is not strictly an imaginary pain.

Notable work by Critchley and colleagues also suggests the sensibility of interoceptive experiences correlates with the subjective emotional experience (Critchley, Wiens, Rotshtein, & Dolan, 2004). The awareness of inner bodily feelings eventually affects the ability to process emotions. Interoception sensitivity and accessibility are proven to correlate with one's self-awareness, wellness, social behaviors (Wells & Papageorgiou, 2001) and emotions (Barrett, Quigley, Bliss-Moreau, & Aronson, 2004). An emotional attention balanced

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[3] The definition of visceral afferent information: "The general visceral afferent fibers conduct sensory impulses from the viscera, glands, and blood vessels to the central nervous system. They are considered to be part of the autonomic nervous system." (General Visceral Afferent Fibers, 2017)

between inside self and outside world provides a foundation to be self-aware and self-connected. Cognitive therapeutic treatment such as interoceptive exposure helps patients to be more aware of body sensations in situations of panic (Craske, Rowe, Lewin, & Noriega-Dimitri, 1997). Patients with Autism spectrum disorder (ASD) have shown a disproportionate attention to internal cues over external stimuli (Schauder, Mash, Bryant, & Cascio, 2015).

Interoception connects the mind and internal body state, operates between the unconsciousness and consciousness. It is a middle ground between the biological operation for survival and abstract mental experiences. A.D. Craig, a leading researcher in the area of interoception, argues that interoception is intimately linked to the sense of self. The existence of our body and its active state constitute a presentation of "the material me." He proposed the framework of "a progression of integrative representation of affective feelings from the body that lead to an ultimate representation of all feelings in the bilateral anterior insulae," naming this concept "the sentient self" (Craig A. D., 2010). In Craig's work, he extensively examined the functions of human insula as the substrate for sensory representations of affective bodily feelings, integration of the sensory inputs and an ultimate neural instantiation of subjective experiences at the present time. This time-shifting progression of self image is summarized as a cinemascope model as shown in Fig. 2.1, in which the present sentient self is constantly compared with those associated with a future self, a recently experienced self and a remembered self. This cinemascope model suggest the perception of self is dynamic, malleable and deeply rooted in body experiences. In addition, the comparator buffers (Fig. 2.1) suggest that the perception of self is always one step later that the present, as beautifully described by Antonio Damasio:

> *"At each moment the state of self is constructed, from the ground up. It is an evanescent state, so continuously and consistently reconstructed that the owner never knows it is being remade unless something goes wrong with the remaking. The background feeling now, or the feelings of an emotion now, along with the non-body sensory signals now, happen to the concept of self as instantiated in the coordinated activity of multiple brain regions. But our self, or better even, our metaself, only 'learns' about that 'now' an instant later. ... Present continuously becomes past, and by the time we take stock of it we are in another present, consumed with planning the future, which we do on the stepping-stones of the past. The present is never here. We are hopelessly late for consciousness."* (Damasio, Descartes' error: Emotion, rationality and the human brain., 1994)

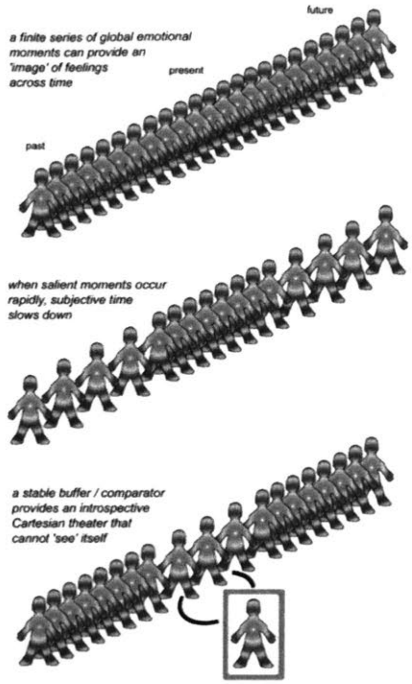

Figure 2.1 A cartoon illustrating the cinemascopic model of awareness based on time-shifting global emotional moments (top), which can explain subjective dilation of time (middle), and which provides a possible basis for subjectivity with a comparator buffer (bottom) that can be loaded with the present global emotional moment for comparison with any other from the past or future, but which is always one tick behind when compared with the present moment. *(Craig A. D., The sentient self, 2010)*

2.1.3 Embodied Emotion

Theoretical interest in the link between interoception and emotion is undergoing a renewal of interest because of interoception's theoretical connections to emotion. (Wiens, 2005) These internal body feelings are believed to connect with our emotions, as so-called "embodying emotion" (Niedenthal, 2007).

In 1890, William James hypothesized that emotions are our perception of physiological changes (James, 1890). As Joseph LeDoux describes of William James's *Emotion*: "The mental aspect of emotion, the feeling, is a slave to its physiology, not vice versa: we do not tremble because we are afraid or cry because we feel sad; we are afraid because we tremble and are sad because we cry." (LeDoux, 1998) Stanley Schachte and Jerome E. Singer later proposed the two-factor theory of emotion stating that emotion is based on two factors: physiological arousal and cognitive label (Schachter & Singer, 1962). In their argument, the generation of emotion (e.g., fear) is built on the presence of both physical experience (heart racing, sweat and fast breathing) and a corresponding cognitive label of the stimuli (a dangerous snake) at the moment.

Nonetheless, researchers found evidence against the influential two-factor theory of emotion. Marshall and Zimbardo's study shows that the presence of an euphoria confederate[4] had little impact on the subject's compared to a neutral confederate[5] (Marshall & Zimbardo, 1979). In another study by Maslach, hypnotic suggestion was used to induce arousal as a substitute for injecting epinephrine (which causes respiration, an increase in blood pressure and heart

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4 The detailed description of the euphoria confederate from Marshall and Zimbardo's study: "*The programmed "euphoric" script of the confederate, both verbal and nonverbal, followed this approximate chronology (which began within a minute after the subject's injection):*
1. Minutes 1 through 3. Looks around, examines materials on the table, sketches or doodles, hums.
2. Minutes 4 through S. Crumples paper into a ball, tosses it at wastepaper can; repeats with a couple more sheets of paper; gets up, retrieves misses, tries different types of shots from different positions; tosses one to the subject, inviting him to try a shot.
3. Minutes 6 through S. Sits down again, picks up a piece of paper, makes a paper airplane and flies it; makes another one, flies it; retrieves plane from the floor and flies it in the direction of subject; repeats flying plane.
4. Minute 9. Notices and tries a swivel-type foot exerciser on the floor.
5. Minutes 10 through 12. Picks up paper airplane, sits down and plays with materials on the table; makes a slingshot with a rubber band; tears off a piece of the airplane to use as "ammunition" and shoots it at a clock on the far wall; while retrieving shot, notices old, empty folders on a piece of equipment and sets them up as a target; makes more "ammunition" and continues to shoot at the target.
6. Minutes 13 through 15. While picking up "ammunition" from floor, notices hula hoops against the wall behind some exercise equipment (in the adjoining physical therapy room), picks one up and tries a couple of times to rotate it freely around his hips, and then spins it across the room toward the subject; continues spinning the hoop on the floor until the sound of a door opening indicates the experimenter's imminent return; replaces hoop and returns to his seat (Marshall & Zimbardo, 1979)."
5 The detailed description of the neutral confederate from Marshall and Zimbardo's study: "*The confederate, instead of acting in a euphoric manner, offered no dramatic cues as to his emotional state. When the subject and confederate were brought together in the waiting room after the injection, the confederate casually removed a paperback book from his back pocket and proceeded to read it for the entire waiting period. He responded in a friendly, pleasant manner to any questions that were asked, but then returned to his reading* (Marshall & Zimbardo, 1979)."

rate). The subject reported negative emotion in the case of unexplained arousal, even though they are accompanied by euphoric confederates (Maslach, 1979).

In light of new studies, researchers came to a consensus that the emotional experiences are affected (that is, not fully determined) by body signals. In 1994, Antonio Damasio formulated the somatic marker hypothesis, a theory that emotions and their physiological signals influences decision making in life, both positively and negatively, often unconsciously. He created the Iowa gambling task[6], a physiological experiment that simulates real-life decision making to examine the somatic marker hypothesis (Damasio, Everitt, & Bishop, 1996).

In Virginia Woolf's novel *Mrs. Dalloway,* she describes that a nurse talks to her patient "deeply, softly, like a mellow organ, but with a roughness in her voice like a grasshopper's, which rasped his spine deliciously and sent running up into his brain waves of sound." The description sounds similar to a recent online video phenomenon named after the sensorial experience it generates, Autonomous Sensory Meridian Response (ASMR) (Barratt & Davis, 2015). ASMR is a subjective experience with europia feelings and static, tingling-ish sensations on the body, that can be triggered by acoustic stimulus without specific emotional content. Though ASMR is not clinically examined yet, there is already a large online community who claim to experience ASMR and create video, audio content to trigger it. The pleasure produced by ASMR is spontaneous. I also found myself particularly enjoying the quiet, repetitive sounds of someone turning the pages of a book and whispering the titles. How could such a mundane moment be so enjoyable?

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[6] The Iowa gambling task uses a card game to discover a physiological response to a player's poor prospects before the player is consciously aware of those poor prospects. This provided evidence for the somatic marker hypothesis. In the experiment, the subjects are asked to play a game in which they could pick a card from 4 different decks. The decks differ from each other in the number of trials over which the losses are distributed. There are some bad decks that lead to more losses over long run and the others are good. For healthy participants, they would develop the sense of only picking on the good decks after 40 or 50 selections. More interestingly, long before the conscious recognition of good and bad decks, the subjects' galvanic skin response already shows "stress" when their hand hovered over the bad decks. This physiological response is not present in patients with lesions in ventromedial prefrontal cortex and they played deficiently. The somatic marker hypothesis suggests that the decision making is regulated by emotion-based biasing physiological signals, such as the changes in skin conductance, even when the subjects are unaware of them.

The full mechanisms of emotion are still under debate. Nonetheless, there is consensus that awareness of our interoceptive percepts, such as heart rate and respiration, influences our feelings (Critchley, Wiens, Rotshtein, & Dolan, 2004). For example, we recognize excitement when we perceive a fast heart rate and hard, jerky breaths; or, we experience calmness in the case of a slow heart rate and smooth, deep breaths (Costa, Adams, Jung, Guimbetiere, & Choudhury, 2016).

A specifically induced physiological state can influence an individual's emotional responses to stimuli. In the process of *misattribution of arousal*, people mistake what is causing them to feel aroused (Cotton, 1981). Studies have demonstrated that a person experiencing a racing heart rate induced by exercise (White & Kight, Misattribution of arousal and attraction: Effects of salience of explanations for arousal, 1984) or fear (White, Fishbein, & Rutsein, 1981) could conflate that sensation with sexual attraction. The male subject standing in the middle of the high-altitude bridge attributes a stronger impression and even romantic preferences towards the female partner due in part to the feelings the bridge induces on the male. White has an explanation for this phenomenon: the experience of heart racing and intense breath caused by fear is similar to the physiological responses under the condition of sexual arousal.

Thus, the physical sensations we experience are not simply the result or manifestation of emotion, but part of its origin. An emotion, such as joy, has to be a fusion of its motivation, cause, expression and everything that occurs at the moment. When a smile occurs, it is not only the expression, it is essentially what is expressed. Silvan Tomkins coined the term inverse archaeology which emphasizes surfaces (face) and surface features (facial affect) which determine our individual perceptions. In his final public lecture, "Inverse Archaeology", at Rutgers on July 15, 1990, he said, "*Archaeology digs deep to bring fossils and artifacts of the past to the surface . . . I assume . . . that the surface of the skin is where it is at, not deep within us, that the skin is the major motivational organ, and that a smile is where it appears to be. It is not in a group of happy cortical neurons, nor in the folds of the stomach. But like the pain of torture, the pleasure of sexual seduction, or the irresistible sleepiness at the site of the eyelids, that region is the site of exquisitely sensitive receptors on the surface of the skin, whether we're talking about drives or pain or affects or whatever. The centrality of this organ, this skin, somehow, which is right under our noses, we have failed* *to properly evaluate."*[7] Similarly, I would argue that the expression of self, no matter if it is heart racing or sweating, is the self to be expressed.

2.2 Self in the Mirror

Figure 2.2 Hand With Reflecting Sphere, by M.C Escher

In *Hand With Reflecting Sphere*, a self-portrait by Dutch artist M.C Escher, the artist and his surrounding environment are trapped in the reflective sphere. He, along with us the viewers, looks into the curved reflection of himself and the studio he lived in. The reflection is distorted but recognizable, false but true, real and dreamlike. In a quick moment, I come back to myself and see my own images in the mirrors. They, in the end, are the virtual crossing points from the opposite extension of the light. The light doesn't exist on the other side, but only in front of the mirror. How are we so certain that the face in the mirror, in the Photoshopped picture or in the front camera of iPhone, is truly ourselves?

In fact, the ability of recognizing oneself in the mirror is not universally shared. The mirror self-recognition test is a traditional method to measure self-awareness among non-human animals. In 1970, Gordon Gallup experimentally investigated

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[7] On July 15, 1990 Silvan Tomkins gave the plenary address to the annual conference of the International Society for Research on Emotions.

the possibility of mirror recognition with chimpanzees. By painting a visual marker without any olfactory or tactile cues on the chimpanzees, he observed an increased frequency with which the chimpanzees spontaneously touched the marked areas on their body when there is a mirror present (Gallup, 1970). Similarly, a human child who touches rouge painting on her nose looking into the mirror demonstrates a basic understanding of self recognition and self knowledge (Amsterdam, 1972).

To register the image in the mirror as ourselves, we rely on the expected, stable visual contents and synchronized actions. The reflected image is bound to follow its original. But the reflected image is nonetheless dynamic, possibly turning in opposition to what it was in the past. In *Seeing through clothes*, Anne Hollander examines how the presentation of our body and clothes changes the visual perception and aesthetics of each individual and within a group. Andy Clark and David Chalmer, authors of *The Extended Mind*, argue that a person and her environment participate in a coupled system in which physical surroundings influence thought. The sea of spoken sentences we live within shapes the linguistic uses and the carried notebook turns into part of the memory. Similarly, the concept of self inevitably grows from looking into the mirror and seeing oneself everyday.

To further investigate the relationship between the internal self and a perceived self, I'd like to extend the concept of *mirror*. It consists of more than visual reflections: a mirror, literal and figurative, can support sensory feedback (sensory reflection). As a person makes a sound by either interacting with the surroundings (eg. tapping, walking) or producing it directly (eg. voice, respiration), the sound will be heard by the person again. The heard soundscape is an auditory self-portrait. The auditory feedback serves in a wide range of physiological and psychological experiences, contributing to self cognition, knowledge and examination.

For example, each person identifies their own voice. The unique timbre of human voice is not only due to the actual shape and size of an individual's vocal cords. The size and shape of the rest of that person's body and the manner in which the speech sounds are habitually formed and articulated also define a voice. A trembling voice connects with fear and uncertainty while a stentorian voice illuminates excitement. If the auditory feedback loop gets hijacked, perceptual disorders such as self-recognition deficits[8] in schizophrenia appear. Psychiatric

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[8] Theories about auditory hallucinations in schizophrenia suggest that these experiences occur because patients fail to recognize thoughts and mental events as self-generated. Waters, Flavie, et al. "Self-recognition deficits in schizophrenia patients with auditory

patients with self-recognition deficits sometimes believe they are haunted because they hear random voices without acknowledging that the sound comes from themselves. An interesting experiment by Ana Tajadura-Jiménez also shows that the representation of key properties of one's body, like its length, is affected by the sound of one's actions (Tajadura-Jiménez, Väljamäe, Toshima, Kimura, Tsakiris, & Kitagawa, 2012). Similarly, changes in footstep sounds influence the perception of one's own body shape. In another study, Ana Tajadura-Jiménez provided subjects synthesized footstep sounds which synchronized with their steps and asked them to draw their own body silhouette on a computer. The increased volume of footstep sound results in a larger drawn body shape (Tajadura-Jiménez, Basia, Deroy, Fairhurst, Marquardt, & Bianchi-Berthouze, 2015).

2.3 Self in Alienation

Up to now we see that the bodily self-consciousness tightly connects with our subjective, emotional experience. The perception of our own body isn't purely an internal process but incorporates external information, and it is never fixed but malleable as time goes by. In this chapter, I will discuss the techniques that researchers have explored for altering the perception of self and their implication for our relationship with oneself.

2.3.1 Interoceptive and exteroceptive cues

Considering sensory signals, I want to first distinguish between interoceptive and exteroceptive cues:

Interoceptive cues, as explained in Chapter 2.1, center around *the sense of the physiological condition of the entire body.* In a simplified way, interoceptive cues deal with signals that come from and are produced inside of our body, such as headache, hunger, high blood sugar and heart rate. Study participants are often asked to exercise or take drugs, such as lithium chloride poisoning (Pappens, Van den Bergh, Vansteenwegen, Ceunen, De Peuter, & Van Diest, 2013), to obtain changes in interoceptive experiences.

Exteroceptive cues, on the other hand, are perceived through the senses that primarily connects with the outer world. These stimuli can be artificially

hallucinations: a meta-analysis of the literature." *Schizophrenia Bulletin* 38.4 (2012): 741-750.

introduced and controlled in a large variety and high complexity, including sound, touch, temperature, smell and visuals among many others.

Most of the time, interoceptive and exteroceptive cues are perceived together. For example, when we raise an arm out front. It is an experience that incorporates seeing the arm moving, a sense of proprioception of muscle motion and the tiredness from the muscle tension. There has been research looking at the functional differences in neural substrates for conditioning by exteroceptive and interoceptive cues (Jensen & Smith, 1985). Though I distinguish the completed systems based on their use of interoceptive and exteroceptive cues, there is no in-depth discussion nor studies around the differences in the scope of this thesis. This is future research.

2.3.2 The second heart

Cardiac activity is one of the better understood interoceptive experiences. We have comprehensive models of heart-brain interaction through biological, neuropsychological and social cognition measures (Di Pasquale & Pinelli, 2012). As mentioned above, counting one's own heart rate without external stimulation or feedback is widely used as a quantitative method to assess level of self-awareness. However, the cardiac and respiratory systems are still not fully examined due to their complex dynamics with continuous noisy fluctuations. Moving beyond the one and only heart of a person, researchers are studying a "second heartbeat."

A case study of C.S, a patient with an external heart (an extracorporeal left-univentricular cardiac assist device, LVAD), was published in 2014. In the study, when the patient is asked to detect his heartbeat with no external stimulation or feedback, "*he seemed to be guided by signals from the artificial LVAD, which provides a somatosensory beat rather than by his endogenous heart.*" Later on, "*he accurately performed several cognitive tasks, except for interoception-related social cognition domains (empathy, theory of mind and decision making).*" (Couto, et al., 2013)

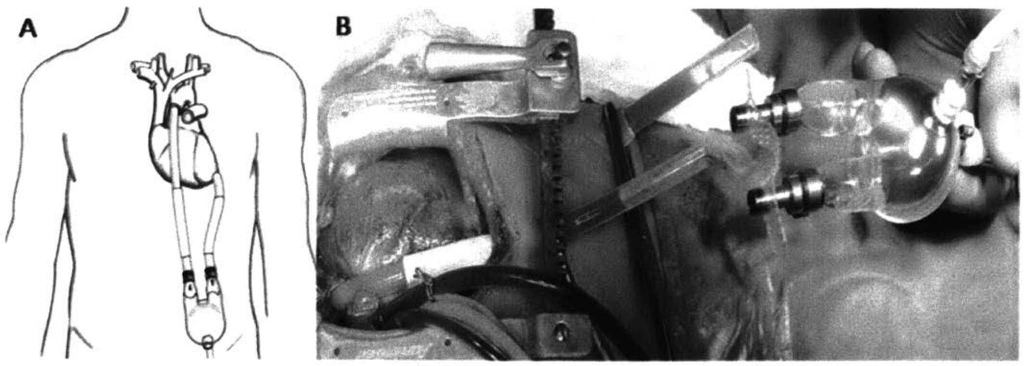

Figure 2.2 Schematic and picture of the LVAD implantation procedure. (Couto, et al., 2013) (A) Schematic view of the LVAD with the pump lying over the patient's abdominal skin and canulae connecting it to the apex and aortic artery. (B) Implantation procedure; canulae can be seen exiting from the thoracic cavity to the abdominal skin and connecting to the pump. Images provided by Berlin Heart.

The study sounds like science fiction. The prosthetic body parts ultimately change the mind; the foreign sensation from an artificial heart interferes with the internal connection to oneself.

Similar alienated experiences can be achieved using less invasive methods. This is called *false interoceptive feedback*. False external heart rate feedback can influence cognitive and emotional judgments just as the real heart does:

Jean and Tanzeen from Cornell University recently presented a thoughtful study of false tactile feedback of heart rate information and its measurable impact on anxiety levels. Participants were asked to wear a wristband that produces vibrations at a frequency of 60 bpm, but they were informed that the vibrations would always represent their current heart rate. The participants who felt the slow heart rate (60bpm) vibration had a lower anxiety score change before and after a modified Trier Social Stress Test[9]. (Costa, Adams, Jung, Guimbetiere, & Choudhury, 2016)

A classic study by Valin presented high-level emotional effects of false heart-rate feedback and implied that social behavior and sexual arousal could as such be manipulated. In the study, male subjects heard sounds portrayed as their hearts

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[9] The Trier social stress test (TSST) is a laboratory procedure used to reliably induce stress in human research participants. In the test, the participant is asked to do a public speech for five minutes in front of a group of judges performed by the experimenters, which is often framed as part of a job interview. If the participant does not use the entire 5 minutes, the judges will ask him or her to continue till the end.

beating while viewing slides of seminude females from Playboy magazine. Their measurements indicated that subjects were more attracted to females in the slides if their "heart rates" were inflated at the time. (Valins, 1966)

2.3.3 Whose body?

Body ownership is the perceptual state of one's own body. It connects with the sense of agency ("I am causing the action.") The senses of body ownership and agency originate from the temporal congruence between different sensory and motor signals. For example, we expect our arm will rise and the index finger will stretch forward when the action of pointing is commanded by the mind (Tsakiris, Longo, & Haggard, 2010). A distinction proposed by Gallagher states that the sensory events related to the body constructed the sense of body ownership; by contrast, the voluntary motor actions correspond to a sense of control or agency, though the voluntarily generated motor actions are often accompanied with sensory signals ("I see my hand moving").

The sense of "This is my body" is temporal. Every event and its corresponding signals happen jointly at the present. The temporal characteristic of body image makes it possible to create interventions on body ownership within a short period of time. In his framework of the sentient self, A. D. Craig also suggests that the frame rate of each homeostatic self image is shifting at an approximate rate of 8 Hz. There are also well-known studies that use synchronized multimodal perceptual stimuli to alter body representation and create body ownership illustration (BOI): the rubber hand illusion, in which watching a rubber hand being stroked synchronously with one's own unseen hand causes the rubber hand to be attributed to one's own body (Botvinick & Cohen, 1998); and mirror-touch synesthesia (Banissy, Kadosh, Maus, Walsh, & Ward, 2009), in which watching another person's face being touched in the mirror while examining synchronous tactile sensation produces quantifiable changes of mental representation of oneself and dilutes the differentiation with others (Tajadura-Jiménez, Grehl, & Tsakiris, The other in me: interpersonal multisensory stimulation changes the mental representation of the self, 2012).

Notably, the body ownership illusion does not occur when anatomical constraints are violated. When the rubber hand is located outside the participant's peripersonal space, where its posture is impossible, body ownership is not experienced (Lloyd, 2007). In Kilteni's study, ownership over a fake arm in virtual reality is less strong when the fake arm is four times the length of the real one (Kilteni, Normand, Sanchez-Vives, & Slater, 2012).

In summary, acquiring the sense of ownership over an external object requires the convergence of two main kinds of information: (1) the *current* bottom–up processes of congruent multimodal perceptual cues and (2) the modulating top–down body image based on a flexible but still robust *previous* internal body representation that requires preservation of key anatomical constraints in terms of body shape and visual perspective.

These experiments and illusions generated considerable interest as they challenge the conventional understanding of an intrinsic, rigid body representation of self. The sensorimotor functions of the body are no longer just low-level processes but tightly connected to higher functions such as self-awareness, agency and social cognition.

While imprisoned in the castle, Persian polymath Avicenna wrote his famous "Floating Man" thought experiment to demonstrate human self-awareness and the substantiality of the soul (Goodman, 2006). In the experiment, he asks his readers to imagine themselves suspended in the air, isolated from all sensations. Avicenna argues that, in this scenario, one would still have self-consciousness. He thus concludes that the idea of the self is not logically dependent on any physical thing, and that the soul exists independently. Re-thinking the floating man experiment now, I would imagine the sense of self gets blurred if we are left without sensory signals: no heartbeat, no breathing.

3. The struggle and desire for the self

Last chapter puts the thesis in context and presents a series of scientific research concerning the perception of self from its physiological and sensory perceptive. In this chapter, I expend the horizon of discussion by situating the sense of self in relation to the society one lives in. By examining the struggle and desire shared in the society for onself to be "better", I point out the necessity of being sensitive to oneself.

3.1 Reorganized Self

In the SEEING / SOUNDING / SENSING symposium hosted by the MIT Center for Art, Science & Technology in 2014, Professor Alva Noë discussed the concept of "organized activities," a concept examined in depth in his book *Strange Tools: Art and Human Nature*. He asserts that these organized activities are deeply rooted inside human society. "Our lives are one big complex nesting of organized activities at different levels and scales... We are always captured by structures of organization[10]." (Noë, 2016) Noë gave the examples of breastfeeding and dancing as organized activities which need to be analyzed at the "embodied level," a process leaping among and spreading through the biological, perceptual and cognitive processes.

An illustrative example is dancing. Dancing is a first-order organized activity, but choreography "put(s) dancing on display." At the same time, choreography changes the perception of dancing and further changes the way we dance. It *re-organizes* dancing. Similarly, art, as Alva writes, provides "a way to understand our organization and, inevitably, to reorganize ourselves." These constant back and forth (and inevitable) activities of organizing and reorganizing accompany with our growing up.

In Noë's work, he emphases the intersubjectivity of organized activities as it needs to be understood socially: "To be alive is to be organized, and insofar as we are not only organisms but also persons. We find ourselves organized, or integrated, in a still larger range of ways that tie us to the environment, each other, and our social worlds." The organization possesses an interexchange relationship between individual entities. But as I discussed in the first chapter, the perception

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[10] Organized activities, in Noë's definition, obtain six features, they are: 1) natural and primitive, 2) of sophisticated cognitive capacity, 3) temporally dynamic, 4) emergent from endogenous dynamics (in the case of breast-feeding neither nurse nor infant is in charge), 5) functional and 6) potentially pleasurable.

of self is neither predetermined nor isolated from the external/internal world. It is closely influenced and dependent on the body we possess, as well as the environment and society we live in. Thus I see the day-to-day sense of self as an organized activity, and I'd propose my thesis, altering the perception of self, as an attempt to reorganize ourselves.

3.2 Conflicted and Governed Self

As organisms, much of our life is organized by primitive activities that are life-supporting, spontaneous and involuntary. We are absorbed into such activities; they form our biological and existential natures. Our physical body is the base and acting entity of these embodied, basic actions. These actions then support social activities. However, modern political/social movements and ideologies often adopt a disembodied approach to their subject matters. The body has historically been considered as the passive receptor of social control. In this chapter, I examine the body as the center of social actions. The interdependence between the sociology and biology of body will be discussed in the context of feminist theory and governmentality.

In gender theory, individuals are gendered in the society and the sex-linked biological body is transmitted into a cultural identity. Though biology determines a human's chromosomal and anatomical sex (male, female or biological intersex), the state of being identified as a woman, a man or others is defined by the individuals themselves. However, on an individual level, the process of self-redefinition is never divorced from its biological substrate. In fact, people sometimes seek for surgery and alteration of the physical body.

The tyranny of biology deeply affects human activities. In social construction, the body tends to be hidden from view, yet nourished and sustained by its surroundings. In her book *Gut Feminism*, Elizabeth Wilson points out that "most feminist research on the body has relied on the methods of social constructionism, which explore how cultural, social, symbolic, and linguistic constraints govern and sculpt the kinds of bodies we have." (Wilson, 2015)

In response to the antibiological bias within feminist theory, Wilson argues that analysis of biological and pharmaceutical data could, in turn, benefit feminist theory. She demonstrates that biology and culture are structurally inseparable by examining the use of antidepressant drugs, the speech of organs (constipation and diarrhea) and how transference is biological. (Wilson, 2015)

The arts make a similar statement about the biological body, identity and gender: that biology and culture are structurally inseparable. Artist Eleanor Antin and Cassil both performed a body modification piece through diet and exercise in weeks and months, while their goals differ from each other: weight loss versus transforming into a masculine muscular form, respectively. Eleanor's work borrowed the idea of "carving" in traditional process of Greek sculpture but used her own body as the material. Her body was a physical manifestation of the pressures put on women's body shape in society. On the contrary, Cassil's work showcases the cut of musculature as opposed to the cut of the surgeon's knife in the pursue of a trans, muscular body. As the bodies transform throughout the performances, they demonstrate the re-construction of subjective experience and subjectivity conceptually as well as physiologically. Extensive research documents that testosterone, growth hormones (Kern, Perras, Wodick, Fehm, & Born, 1995) and insulin secretion (Schalch, 1967) increase due to acute and chronic exercise and consequently affect the mood, emotion and personality of the subjects. When the equilibrium of internal hemostatics changes as a result of the physical alterations, the image of our sentient self grows into a different one.

Another direction of self alteration centers around the effort of quantified self and self regulation. In his book *The body and Social Theory*, sociologist Chris Shilling argues that "as a result of developments in spheres as diverse as biological reproduction, genetic engineering, stem cell research, nutrigenomics, plastic surgery and sports science, the body is no longer a 'natural given', but more a phenomenon of options and choices." (Shilling, 2012) People gain the power to control the body and, at the same time, have it controlled by society. Though the body is individually maintained, its "ideal" state is a collective decision.

Healthism, a term ironically used by Petr Skrabanek, starts when the governing authorities establish the norms of health and instill in the public the idea of a "healthy" lifestyle (Skrabanek, 1994). It classifies human activities into healthy and unhealthy, approved and disapproved, responsible and irresponsible. The standards of health ostensibly originate from statistics but essentially rejects the diversity of life with a moralistic attitude. Petr argues that healthism justifies racism, segregation, and eugenic control; it is a threat to the autonomy to pursue the individual kind of happiness.

Moreover, the rise of the quantified self has opened up uncharted territories for introspection and self-governance, where the most basic human functions such as breathing, eating, sleeping, walking, and even blinking, have become sites for monitoring and improvement. Norms proliferated by widely used devices and shared by millions of users (e.g. how many blinks per minute is optimal) form the only known maps for navigating these territories to the promised land of self-improvement. Working out and drinking cold kale smoothies have grown to be part of the modern daily routine across continents --- in New York, in Tokyo, in Urumqi. The choices individuals make are reshaping the collective idea of how each other should be. This homogenized life among individuals means, for Noe, "We are lost in schemes of organization of which we are not the author and about which we command no clear understanding." (Noë, 2016)

3.3 A sensitive self

My experience wearing a new pair of boots always starts with me celebrating during the first hour. But soon the friction accumulates, and the skin surface gets red and sensitive. In most cases a blister develops within two hours, and things get really bad when the blister breaks. Walking is basically torture from that point on. The pain comes each time I take a step when the stiff structure directly presses onto the already inflamed skin. I become extremely sensitive to the inner structure of the shoes, the shape of my foot, how the steps would squeeze my feet (contact area, pressure, duration). My body starts to adjust its posture and actions: the knees slightly bend to shift the center of gravity a bit forward, toes tightly grab the bottom surface thus the landing starts from the forefoot, leaving the ankle some space from the shoe counter. All these would go away after the shoes are worn enough and reshaped by the foot. They get soft and tender at the points in touch with me and hold the stiffness elsewhere. Because of the pain experienced, I always empathize with ladies even though they look glamorous in heels.

The pain I undertake for each pair of them is an inevitable procedure to obtain a foreign object to myself. It also lets me get to know myself better: My right foot is slightly smaller than the left. I drag my foot on the ground often while walking. My feet get bigger and swollen mostly between 8 - 9 pm every day. This knowledge comes from the attention I give as a result of pain and discomfort. However, I always, again, forget about them very quickly once the shoes break in. It is one of the unfortunate facts in life: comfort brings insensitivity.

In a conversation for Commonplaces, anthropologist Zoe Wool and artist and activist Nick Dupree had a discussion around Nick's breathing tube. Nick is on ventilation in order to survive. Zoe described that she "was struck by how alive the tube itself felt as it wobbled on its own in my hand. ... the feeling of you being breathed, and the tube being breathed, and a whole sociomaterial assemblage in the midst of its animation." In response, Nick talked about the feeling of breathing *by reference*:

"The lungs don't have nerve endings, but we still feel what's going on with them by referencing changes in chest rise and fall, changes in the way that the air moves in the throat (which does have nerve endings) and the way breaths play against the carina (that weird flat place where the two primary bronchi meet, borderline above the lungs) which has some sensation, at least for me. The tube is, in a way, experienced as something akin to a hair: the tube moves or pulls or is touched, I feel it acutely with great sensitivity from its 'root.' Meaning you move the tube anywhere or touch the tube even two feet down, I get feedback in the tracheostomy that I feel, feeling by reference." (Wool & Dupree, 2014)

I envy the sensitivity Nick has with each breath as I seek for this kind of self-awareness in my prosaic daily life. Sensitivity brings light to the insipid details, to the repetitive tasks, to the ignorance, prejudice and numbness. Pearl S. Buck believes the sensitivity in an artist, saying "the truly creative mind in any field is no more than this: A human creature born abnormally, inhumanly sensitive. To him (and her) ... a touch is a blow, a sound is a noise, a misfortune is a tragedy, a joy is an ecstasy, a friend is a lover, a lover is a god, and failure is death." (Iglesias, 2001)

4. Being A Tree: habituating to another self

In this thesis, I further develop the theories and hypotheses around the sense of self by creating experiences that challenge the sense of self and the psychological and emotional states of the participants. There are two built projects in this thesis that use exteroceptive and interoceptive signals, respectively, to alter the perception of self. Being a tree focused on the multisensory stimulation of exteroceptive signals and create a temporary body experience illusion as if the audience was a tree.

The concept of being a tree originates from my research around the Body Ownership Illusion (BOI). As mentioned in Chapter 2, BOI, the illusion of owning or being inside another body, was previously examined in the famous rubber hand illusion experiment (Botvinick & Cohen, 1998), and now is often induced using virtual reality (VR) (Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2008). Through a systematic alteration of our body sensory stimuli - vision, touch, motor control and proprioception - the brain is tricked to inhabit bodies and body parts different from one's own. BeAnotherLab has been using embodied experience in VR to explore the relationship between identity and empathy from an embodied perspective. Their project *The Machine to Be Another* allows the audience to experience the world from the perspective of another. By swapping the virtual bodies, two people interact with "themselves" through the lens of the other. The possibility of inducing BOI for an extended-humanoid or non-humanoid avatar has been investigated as well and referred to as Homuncular Flexibility (Won, Bailenson, Lee, & Lanier, 2015), the idea that the homunculus—an approximate mapping of the human body in the cortex—is capable of inhabiting and controlling novel bodies, such as a virtual human body with a tail (Steptoe, Steed, & Slater, 2013), with a third arm or a virtual lobster (Lanier, 2016).

Compared to other creatures with complicated kinetic motions, trees may seem static. Yet, they are full of life. In this project, I want to bring out the liveness of a tree and take the audience from its beginning of life till the end. Together with several colleagues, we created a sensory-enhanced VR experience in which a person inhabits a tree—indeed becomes a tree—seeing and feeling their arms as branches and their body as the trunk. The story goes through the life cycle of the tree—from a seed rising through the dirt, to sprouting branches and growing to full size, until finally it is destroyed by fire. I called this project TreeSense. Then, in October 2016, we started collaborating with movie directors Milica Zec and

Winslow Porter to push TreeSense further and to develop a hyper-realistic VR film, called *Tree*.

Both the TreeSense and *Tree* project are the result of a close collaboration between Yedan Qian and myself. TreeSense received the Student Runners Up (second prize) at this year's Core77 Design Awards and it will be shown at Design Dubai Week in the fall. *Tree* was selected for both the Sundance and TribeCa Film Festivals in 2017.

4.1 TreeSense

In TreeSense, a member of the audience experiences what it feels like to be a tree by *seeing* and *feeling* her arms turning into branches and her body into a trunk.

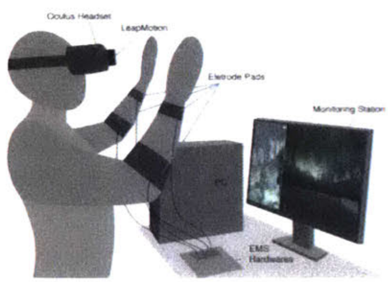

Fig 4.1 TreeSense desktop setup

4.1.1 Seeing

The story of TreeSense is simple. It starts from a seedling, progresses to its fullest form, till the final destiny. We want the audience to be fully immersed inside the environment, seeing the delicate changes of their own body and occasionally being surprised by some friendly visitors (a bird and a caterpillar).

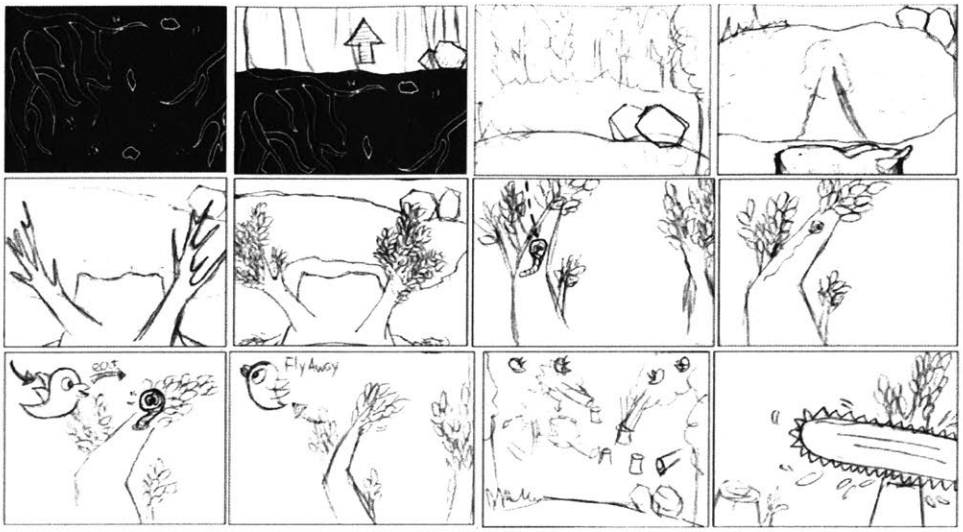

Fig.4.2 TreeSense storyboard

The design of the visuals in TreeSense aims to create a magical atmosphere for the audience. We selected a stunning 3d nature asset package from the Unity store, *Stylized Nature Pack* [11], designed by Mikael Gustafsson. For the generation of tree branches, we utilized the generic tree editor inside Unity. Each branch (finger) grows as an individual tree but at the same time is mapped to the big branch (arm).

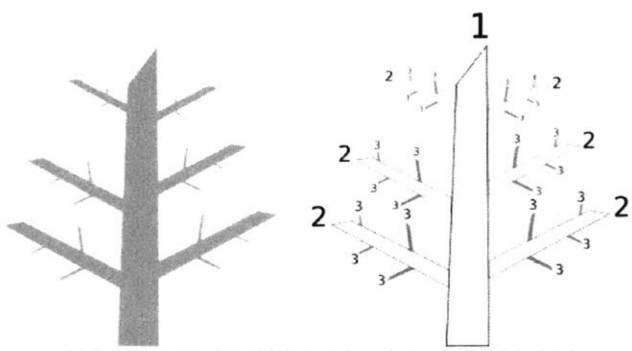

Fig 4.3 The tree level illustration from Unity Manual

The system uses the Unity3D game engine as the center hub to connect all the visual and tactile output as well as the motion tracking input, and to control all the interactions in the experience. The virtual reality content is displayed by the Oculus HMD with the Leap Motion sensor mounted on it. The Leap motion tracks the motion of the hands and forearms, as well as hand gestures and drives the

[11] https://www.assetstore.unity3d.com/en/#!/content/37457

tree's trunk and branches to move correspondingly. The user can use their virtual tree body to interact with virtual objects including a bird, a caterpillar and a chainsaw.

Fig 4.4 Body motions are captured by Leap Motion and rigged to the tree avatar in the virtual world

Fig 4.5 Three main interactions: branch moving, caterpillar crawling and being cut

4.1.2 Feeling

To evoke haptic sensations, such as branches growing, a worm crawling, or a bird landing on the branch (arm), we put electrodes at several key locations on the user's forearms to stimulate muscles and the skin. Throughout the experience, the system delivers various Electronic Muscle Stimulation (EMS) sensations to the user corresponding to the virtual story. In our work, there are three different situations that can trigger EMS sensations: 1) pre-defined hand gestures, 2) interactions triggered by objects, 3) predefined timeline events.

EMS-based devices can generate a wide range of sensations on the body by varying combinations of pulse amplitude, pulse width and frequency of the electrical signal. In our design, we limited the parameters to only trigger non-noxious (non painful) events (Jones & Johnson, 2009). The output current is limited under 50mA, allowing for safe operation. The biphasic signal pulsates at 100-200 Hz with a pulse-width changeable from 60-300μs. Pairs of electrode pads are placed on the forearm of the user and deliver biphasic pulsed electrical currents. The intensity (pulse amplitude) is calibrated per-user with a potentiometer and remains fixed once calibrated.

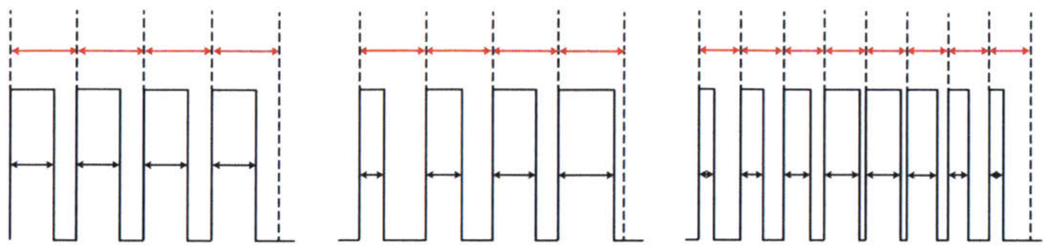

Fig 4.6 EMS signal patterns used in TreeSense

In our system, we designed a series of simulation signals that deliver tactile sensations on and under the skin surface. The frequency is set as the base for the depth and intensity of the sensation while pulse width determines the stimulation pattern of each sensation. We designed three pulse width patterns (Fig 4.6) in our demo:

a) constant pulse width for a static, on/off sensation

b) gradual pulse width for an increasing, moving sensation which matches the tree growth action

c) sine wave pulse width for an alternating sensation

Unfortunately, there is no standard method to determine what the EMS sensation will feel like for each individual. Thus, all the sensorial feedback is determined based on our own experiences after simply trying out different locations on our own arms and those of colleagues. The experiences inevitably vary among people due to the differences of skin conductance, sensitivity and other factors. Thus, before the actual implementation, we provide a 100 Hz, 100ms pulse width stimulation to the audience and adjust the overall intensity baseline of the EMS feedback.

On-skin Sensation

We designed several EMS sensations that imitate what we experience daily on our skin in real life, such as leaves stroking the palm of our hand or an insect moving on our arm. It is created by a low frequency, low pulse-width EMS. When applying electrodes at different locations on the skin, it can induce different sensations, such as feelings of being tickled, numb and stroked.

Force Feedback

The system can also mimic force feedback by quickly applying high pulse-width, short period electrical stimulation for impact effect and low to medium pulse-width, longer period EMS for a consistent force effect. For example, in our work, the audience can feel a bird landing on the back of their hand/branch when the negative electrode is placed at the back of the third and fourth metacarpal bones.

Under-skin Sensation
VR grants us infinite possibilities to probe our perception of body by radically creating sensations that we can never experience in real life. In TreeSense, applied with electrodes on the Brachioradialis muscle with 100Hz, 100ms pulse width stimulation, the viewer experiences a novel under-skin sensation that represents energy flowing inside the limb from the cubital fossa to the wrist, while seeing their branches grow in the virtual environment. When applying higher frequency stimulation (150-200 Hz,100ms pulse width) on the flexor carpi radialis, the viewer experiences the sharp feeling of electricity going through area near cubital fossa when they see their branches being chopped.

Induced Muscle Action
Another novel experience we tried to explore is whether we can create an illusion that a part of our own body is occupied by another living entity. EMS can create involuntary body movements by artificially contracting the user's muscles. In our story, the audiences proprioceptively sense their thumb moving around while seeing a worm swing around at the end of the tree branch. We want to make them wonder whether that part of their body is occupied by another creature. However, the synchronization of induced muscle action and visual element is not obvious to the audience. Though they felt the motions, they did not report feeling the caterpillar as part of their body.

4.2 Tree

While we were developing TreeSense, we were introduced to VR film directors Milica Zec and Winslow Porter when they spoke to our class at the Media Lab. At the time, and by an odd coincidence, they were also developing a similar story about "being" a tree. It was a very exciting bit of serendipity, and we decided to work together in order to transform our ideas into the comprehensive VR film experience, *Tree*. In this project, I took charge of the design and construction of all tactile experiences that are represented throughout the film, while artist Jakob Steensen designed its stunning hyper-realistic visuals. The project is a large-scale collaboration, the detailed credits and exhibition schedule are included on the project website: https://www.treeofficial.com.

Fig 4.7 The visual style of Tree, credit: Jakob Kudsk Steensen

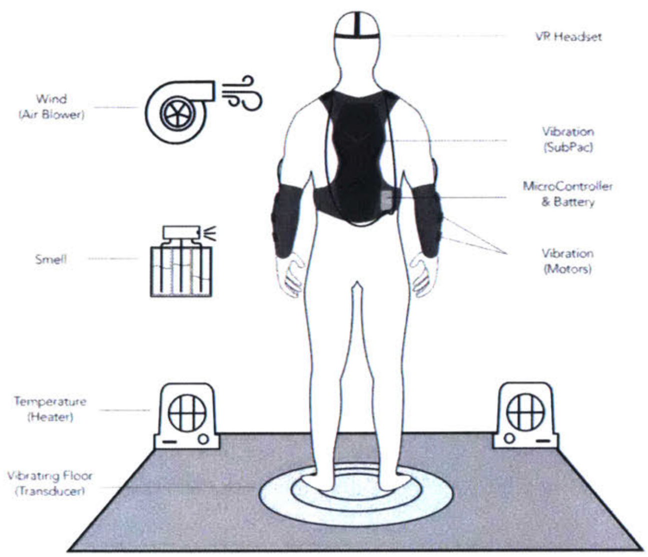

Fig 4.8 Physical Elements in *Tree*

In *Tree*, we follow a more conventional and mature approach because the project had to work reliably for hundreds of people when it was demonstrated in public events such as film festivals. Mostly we used commercial products: The vibrations are presented by Subpac, a pair of customized vibration oversleeves with six local points and a vibrating floor powered by four based transducers. A multitrack bass audio is designed for each part of the body, so that the audience can feel the disturbance of a forest fire as well as a bird landing on a branch. There are additional physical elements, including an air blower to simulate wind and two heaters to create the heat sensation in the final fire scenes. A special improvement of the experience is that we added scents for the first time in TriBeCa festival. Three notes - dust, rainforest and burning - are delivered in sequence. The smell of the environment immediately changed the perception of the audience. Many people told us they forgot they were in a film festival, and instead thought they were in the midst of a forest.

The design of multi-sensory experiences is a complicated process of composition and choreography. We constantly had to make sure the experiences were perfectly synced, both in terms of timing and intensity. There was already high-fidelity visual and audio inside the VR headset, but it was not a trivial thing to add tactile elements to enhance the experience, without distracting or disturbing the user. The whole physical experience is digitally controlled by Max/MSP and Arduino software while communicating with the Unreal engine through Open Sound Control protocol. The tactile, olfactory, and temperature feedback in real life is precisely synced with the visual experience inside the Oculus headset. We went through various iterations to match the virtual visual details with the intensity, texture, and timing of physical experience.

4.3 Being a tree: feedback from the audience

So far, the presentations at film festivals and elsewhere have been very well-received. As an audience member said after feeling immersed in Tree, "You know it's not real but your body really believes it!" We've seen audiences coming out of the VR film experience in tears. It's been exhilarating for me to witness the power of body sensations and affective connection built inside the experience. Interestingly, the physical expressions and motions of the participants varied a lot among individuals. Some of them were very excited and kept looking around their "tree" body. There are also people who are terrified by the height of themselves as a giant tree and could not move at all during the entire film. People have told us they really felt connected with the tree and found its destruction to be terrifying and emotional.

The interest in creating embodied experiences in virtual reality has grown recently. Famous VR director Chris Milk claimed that virtual reality is the ultimate empathy machine that can change the perception of the audience and make them more compassionate, more empathetic. However, I hesitate to say that TreeSense or *Tree* changed the audience. Would they start recycling and using less paper in daily life because of the film experience? I don't know. I see the experience of being a tree as an intervention in body experience, a short getaway from daily life, a chance that one is willing to give the control of their body to an external system. If there has to be a goal at the end of the experience, I wish the moments of pleasure, excitement and fear in the film could leave one more sensitivity to the land and nature around us.

5. Masque: A Misheard Self

Masque is the second and the main project in this thesis. The system utilizes interoceptive cues to mislead the user's perception of themselves. I also conducted two studies and observed quantified changes in their perception of self.

5.1 Hearing Body

When a person hears something, more than just the mechanics of the environment, but also the body and brain are involved in the person's listening experience. The mental representation of our hearing body is constantly updating and morphed into a temporal model that our mind constructs from the acoustic experience. As a person makes a sound by either interacting with the surroundings (eg. tapping, walking) or producing directly (eg. voice, respiration), the sound will be heard by the person again.

Among all the interoceptive experiences, respiration is the only one that we can regulate directly. To help self-regulation and reflection, there are many psychophysical breathing exercises, that, combined with meditation and yoga, are designed to restore natural, smooth breathing appropriate to the physical needs of the body. Deep breathing helps to facilitate relaxation and calms emotional states, while shallow breathing leads to anxiety and stress. A study by Philippot & Blairy also showed that different respiratory patterns could further generate emotions such as joy, anger, fear and sadness (Martin, Seppa, Lehtinen, Toro, & Salmen, 2016).

5.2 Masque Device Design

Masque is a mask-shaped, psychoacoustic device that manipulates respiration sound in order to influence bodily-related emotional state. With high precision and fast speed temperature sensor, Masque detects the breathing activities and plays back a mediated breathing sound synchronously through a bone conduction headphone. The medicated breaching sound is real-time synthesized, thus its breathing rate can be modified by the user at any moment. In our studies, I observed that users easily mistook the false breathing feedback sound as their actual respiration as well as quantified changes in their performances in cognitive tasks.

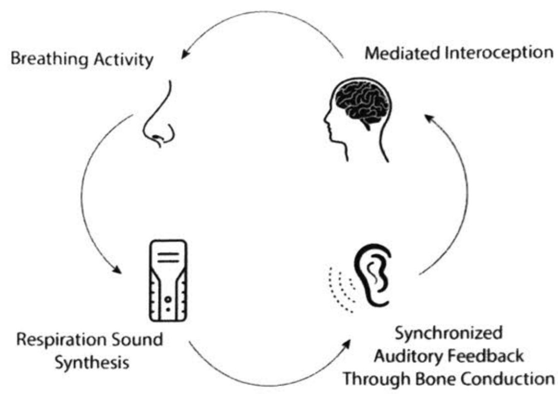

Fig.5.1 Masque system diagram

5.2.1 Respiration Sensing and Audio

Several methods exist for detecting respiration, such as using an elastic stretch sensor around the chest (e.g. Zephyr BioHarness 3) and Ultra-Wideband radar without contact [12]. However, in order to playback audio simultaneously along with the inhaling and exhaling, fast detection of the user's respiration activity is crucial (Gerasimov, 2003). Commercial respiration sensors on the market are either too slow (e.g. Zephyr BioHarness 3 has a 1Hz update rate) or too expensive. In the Masque system I use a digital temperature sensor chip (TSY01, TE Connectivity) for its fast data acquisition and high resolution (0.1°C) . The sensor measures the temperature right in front of the nostril at a frequency of 43Hz to detect the exhaling and inhaling activity of the user. Due to the fast, accurate respiration data from this customized sensor, Masque is able to synchronize the synthesized respiration sounds with the actual breathing activity.

Bone conduction headphones (AfterShokz Sportz 3) conduct sound to the inner ear through the bones of the skull, a process which does not interfere with natural hearing through the air. The nature of bone conducted sound leads some to experience sounds as if they come from inside their own body. A microcontroller (ATmega328) is used for processing and streaming data to a computer, where software programs written in Python and Max/MSP coordinate to detect breathing activities and play back the synthesized sound either sped up or slowed down.

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[12] X2M200 Respiration sensor from XETHRU https://www.xethru.com/shop/x2m200-respiration-sensor.html

5.2.2 Masque Product Design

Fig.5.2 Initial sketches for the device design

The design of Masque draws inspiration from Italian carnival masks. For critics of Commedia dell'Arte, there was a direct connection between covering one's face and hiding one's heart. The visual language of the mask originates in Cesare Pipa's Compendium Iconologia (1593), where the *Fraud* is presented as a monstrous two-headed creature. In one hand he holds a flaming, broken heart—in the other, a mask. I wanted the visual design to imply the inherent tension between self-control and self-disguise in the device.

Fig.5.3 Cesare Pipa's Iconologia (1593), Fraud

Through several iterations, industrial designer HongXin (Sean) Zhang and I landed on a design that carefully conceals all the electronics, including bone conduction transducer, respiration sensor and wires, inside a curved structure. The basic form is 3D printed in nylon plastic using Selective Laser Sintering service from Shapeways. The material is both strong and flexible, making it easy to fit on the head for most people. The respiration sensing element is connected to the main structure through a flexible copper wire for individual adjustment. The bone conduction transducers are disassembled parts from Aftershokz AS400 Open Ear Stereo Headphones. The respiration sensing part is connected to the main structure through a bendable copper wire for individual adjustment.

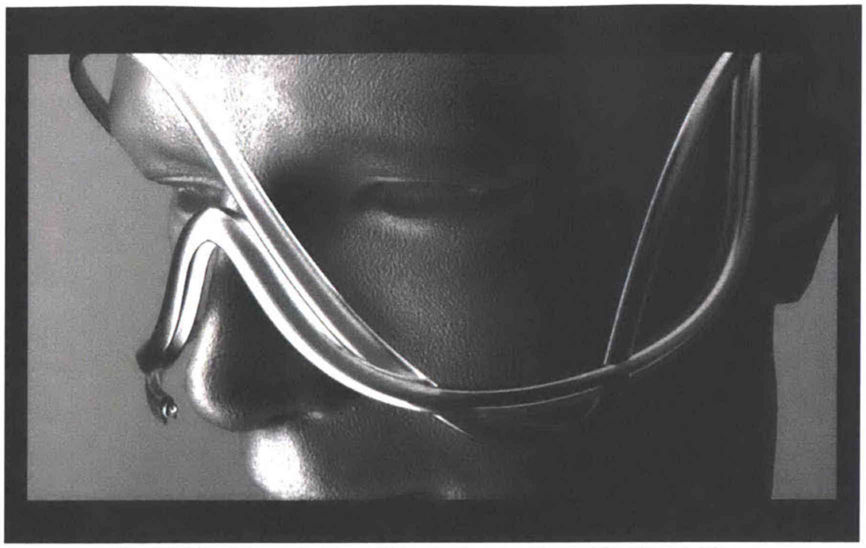

Fig. 5.4 Digital rendering of the design by HongXin (Sean) Zhang

We tried the device on several students for iterative refinement. The final design fit most people except those wearing glasses.

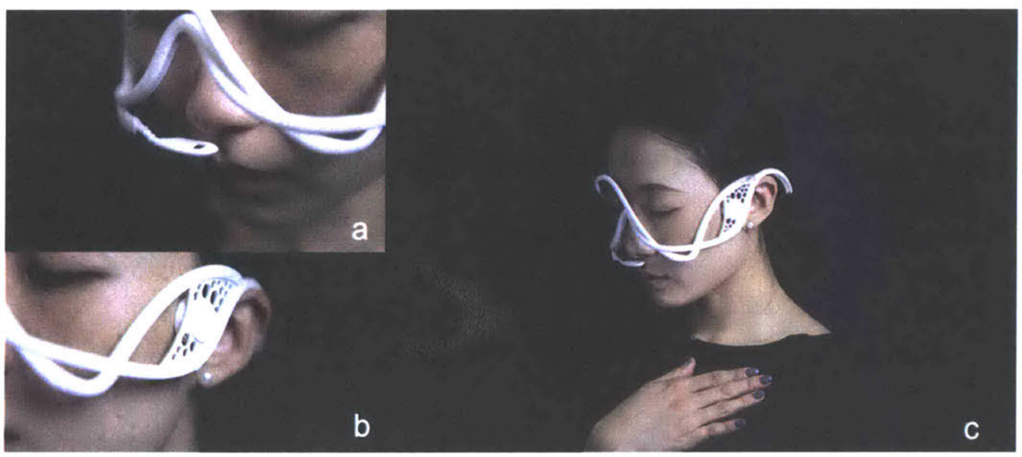

Fig.5.5 Masque hardware system: a) respiration sensor b) bone conduction headphone c) A user wearing Masque

5.2.3 Software

The software system transmits the temperature data from the microcontroller through a serial port to a Python program. The Python program detects an exhale when the temperature starts to increase, shown as the red dots in Fig.5.6. Similarly, the program detects an inhale when the temperature starts to drop, shown as the blue dots in Fig.5.6.

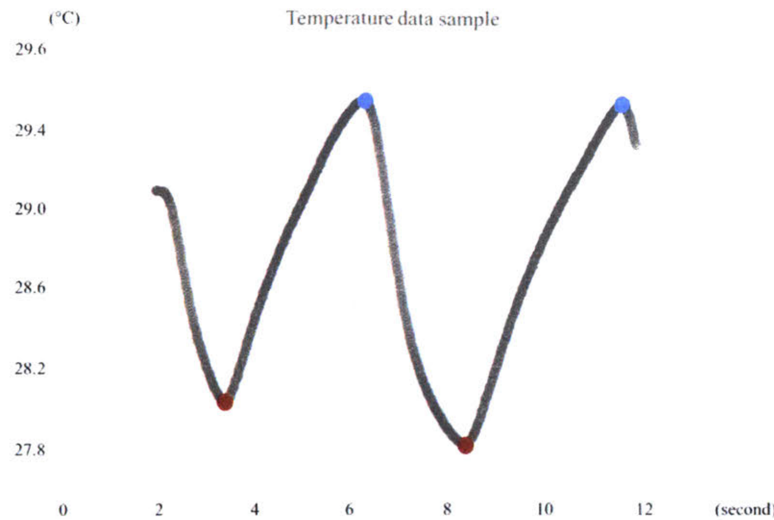

Fig.5.6 10 Seconds of temperature data sample from participant S1.

I chose one sample sound of breathing through the nose as the basic audio sample and reduced its background noise. It is not necessary to sample the participants' respiration sounds individually because nasal breathing sounds are relatively similar across individuals. I manually chopped the sound file into pieces containing only exhaling or inhaling sounds. Each time an exhale is detected, the system randomly picks an exhaling sound clip from a set of four samples and immediately plays it back to the user. Inhaling sounds work the same way.

To change the speed of respiration sound in real time, I included the *diracLE~* library in Max/MSP[13] for time and pitch manipulation. I focused on two parameters: speed and volume. The original sound file is set to be Speed 1 and Volume 1. In the later user study, I used two kinds of sound parameter settings: *fast and loud* (Speed and Volume both at 1.5) and *slow and light* (Speed at 0.7 and Volume at 1). The changing process uses 20 seconds to step down or up, with each parameter changing 0.2 or 0.3 on each step.

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[13] Max/MSP: diracLE~ http://www.timorozendal.nl/?p=434

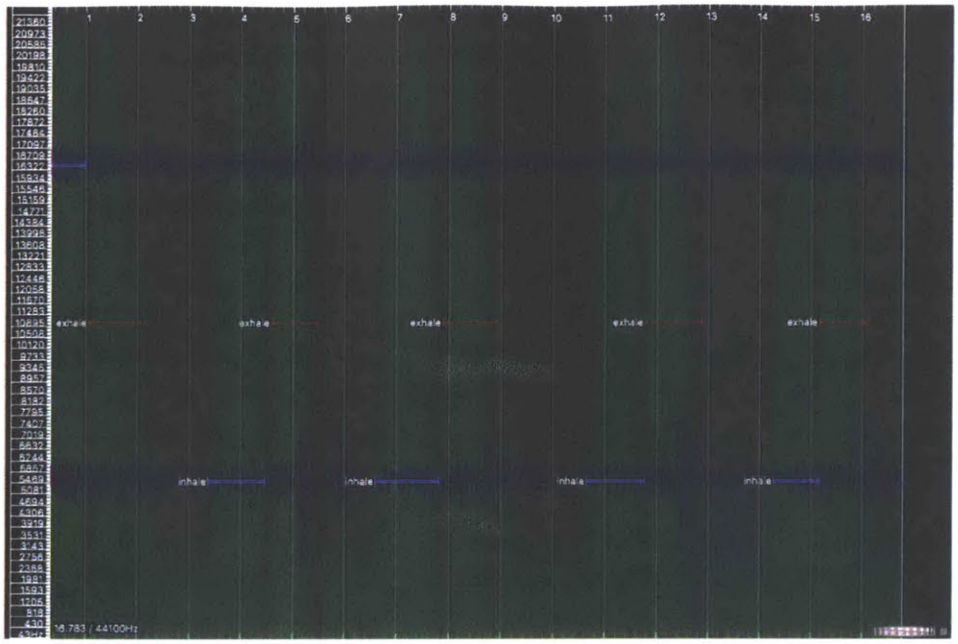

Fig 5.7 Spectrogram of the nasal breathing sound sample and the selected exhaling/inhaling sound clips

5.3 Masque User Study

In the user study, I asked participants to wear an early prototype of Masque which only has the functional parts with electronics. I extended a respiration sensor directly from the Aftershokz headphone using a copper wire.

I sought to answer *four* questions in our user studies:

1. Is the perceptual experience convincing? Will the participants regard the computer generated sound as their own respiration?
2. Does the participant's actual respiration change when hearing the mediated feedback? Will participants unconsciously breathe faster if they hear short breaths or breathe slower if they hear long breaths?
3. Do the participants' cognitive behaviors change when hearing the mediated feedback? Will participants show measurable behavioral differences in different false feedback conditions?
4. Can we influence complex emotional preferences, such as sexual attraction, in participants using false feedback of breathing?

I designed two studies to examine the questions above, which I will refer to as the Stress Study and the Attraction Study. The studies are designed based on our pilot study results as well as previous research. The two studies both examine the bias induced by false feedback but operate under very different emotional contexts, namely stress and sexual attraction. In both studies, the experimenter reminded the participants that they would hear their own respiration when helping them put on Masque. This step was designed to make participants think that their own "breathing sounds" were being played back truthfully.

Before the experiment, a Toronto Alexithymia Scale (TAS) is provided for each participant to measure their ability to identify and describe their emotions (Bagby, Parker, & Taylor, 1994). The TAS scores are used to ensure there are no baseline differences in the ability to experience emotions between the groups.

To get the physiological data, I asked participants to wear a Zephyr BioHarness 3 around their chest. This device measures their heart rate, posture and respiration rate. The participants were also asked to wear Empatica E4 wristbands around their left and right forearms to measure electrodermal activity close to their palms.

After the experiment, I asked all the participants to rate their experience of wearing the devices. Their rating is a 0 to 5 factor (0 as "Very Much", 5 as "Not at all") measurement on how much they agree with the following statements: "The device on my head is comfortable to wear", "The device on my head made me anxious", "I think the device on my head did not affect my performance in this study", "I am very aware of the breathing sound", "I think the breathing sound did not affect my performance in this study". After the questionnaires, we conducted interviews and asked participants about the purpose of study. After they answered all the questions, we then debriefed the actual purpose of study.

5.3.1 Stress Study

I had eight participants in the Stress study, seven females and one male ranging in age from 21 to 40. Participants were told that the experiment was concerned with physiological performance in stressful conditions. I compared the changes in their state-trait anxiety scores between the fast and the slow respiration feedback conditions. The state-trait anxiety scores are calculated based on the State-Trait Anxiety Inventory (STAI), which is a psychological inventory consisting of 40 self report items pertaining to anxiety affect (Spielberger, 2010). The STAI consists of questions such as "I am worried; I feel calm" ,"I worry too much over something that really doesn't matter.", "I am content; I am a steady person."

During the experiment, the participants were first asked to watch a calming video of a slow train ride, shot from the front window of the locomotive for 5 minutes. This phase was used to collect baseline data. After the resting phase, participants were asked to complete the STAI questions. Then participants were asked to take a comprehensive reading test from the GREs in seven minutes, which is much less time than the test is designed for. This was meant to induce stress in participants, in the hope of observing changes in the state-trait anxiety score and physiological changes such as the increase of heart rate and respiration rate. Each participant went through the process twice, once with fast breathing auditory feedback (sound A) and another with slow breathing auditory feedback (sound B). The sequence of these two breathing feedback conditions was randomized.

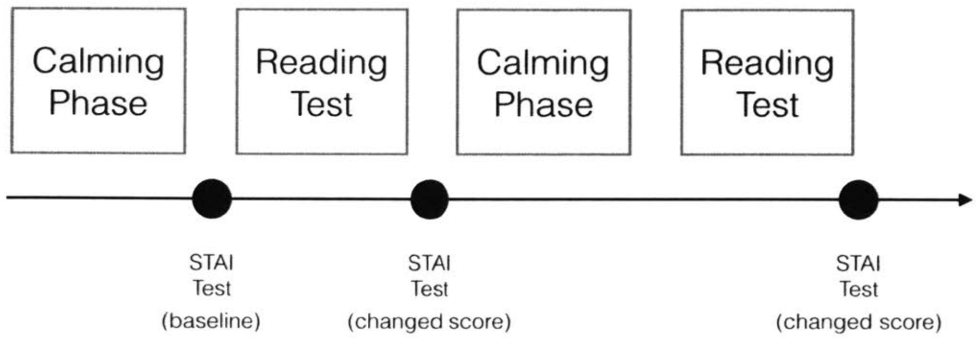

Fig.5.8 Stress study procedure

5.3.2 Attraction Study

The attraction study was an adaptation of Valin's study (Valins, 1966), the widely cited work on manipulating sexual arousal levels in participants through false feedback of heart beat. I recruited twelve heterosexual, male participants from the university, ranging in age from 22 to 45. Participants were told that the experiment was concerned with physiological reactions to sexually oriented stimuli.

Fourteen female photos were selected from photographs published online. The photos are all model headshots of women (5 Caucasian, 2 Latin American, 4 Asian and 4 African American) where the women look straight into the camera with their shoulder skin exposed in front of a white background. Each photo was shown for 30 seconds and the participants were asked to rate the photo on the following characteristics: attractive, exciting and friendly, "How much do you want to date her?", "How much would you want to kiss this person, if you were/are single?" from "Very Much" (score 0) to "Not at all"(score 10).

I am very aware that it is incomplete that the study is only designed around heterosexual male participants. There are several reasons for this decision: The existing literature and previous research around misattribution of sexual arousal have only presented experiments with heterosexual, male participants. I conducted a pilot study in which 5 female participants are asked to rate videos of male counterparts. However, the pilot results are inconclusive. It would be another research topic to construct the basic foundation of the study around female participants or homosexual participants. Due to limited time and resources, Prof. Pattie Maes, Prof. Rosalind Picard and myself decided to focus on heterosexual, male participants as the first study group.

I used the same two kinds of respiration sounds (sound A and B) in the attraction study. During the experiment, the respiration sound feedback changed at the 8th photo. Within 30 seconds, the feedback sound stepped down or up to the other state. Twelve male participants were assigned randomly to perceive the fast sound A first or slow sound B first.

5.3.3 Study Results

I confirmed that there were no initial group differences in TAS scores ($p > .34$ in the Stress Study, $p > .25$ in the Attraction Study) that would affect our results.

5.3.3.1 Perceptual experience of the false feedback

In the post-experiment interviews, I asked participants to talk about what they thought the study was for and then debriefed them on the false feedback system. All twenty participants except two (S2, A8) perceived the respiration sound as veridical or were uncertain about it. Though most of them noticed the occasional mismatched sound and their actual respiration activities, such as a short exhaling sound during a deep breath, the participants took these as glitches and delays in the system, not as a deliberate design. Table 1 shows the participants' ratings of their experience of wearing the devices.

The device on my head is comfortable to wear.	The devices on my head made me anxious.	I think the device on my head did not affect my performance in this study	I am very aware of the breathing sound.	In general, I think the breathing sound did not affect my performance in this study.
2.00 (1.47)	4.00 (0.95)	2.67 (1.68)	1.36 (1.35)	3.24 (1.61)

Table 5.1 Descriptive statistics summarizing ratings on the experience of wearing the devices in both studies.
Average and standard deviation, (0 as "Very Much", 5 as "Not at all").

All participants were very aware of the respiration sound at the beginning, but tended to neglect it later, especially during the GRE tests and the picture rating period. "*I stopped to notice the breathing sound after a bit. It feels just like amplified breaths of mine.*" (A10) "*It took me a while to get used to the breathing but then I forgot about it.*" (S1) Hearing the respiration sound also made the participants pay more attention to their breathing. "*The sound made me more aware of my breathing, it reminds me of doing yoga.*" (A2) "*Hearing the sound makes me very much aware of it.*" (S6). All twenty participants except for one (A6) were not aware of the changes in respiration rate and volume during the experiment. Participant A6 noticed the changing moment when he was not interested in the woman's picture but the breathing feedback got faster. "*I heard my breathing got heavier when I was looking at a picture I am not that excited for.*"

5.3.3.2 Physiological changes during false feedback

I was interested in verifying which of the following two hypotheses was correct: 1) the actual physiological data are affected by the false feedback, thus the changes in behavioral actions in both the Attraction Study (AS) and the Stress Study (SS) could be due to actual physiological changes. 2) the actual physiological behaviors are not influenced by the false feedback, thus the behavioral changes can be understood as purely cognitive results. In his study on false heart rate feedback, Stern observed heart rate differences between the group with stimuli and the control group who heard external sounds but were not informed that this sound represented their heart rate (Stern, Botto, & Herrick, 1972). The presence of heart rate information caused the participants' physiological responses. To further understand the phenomenon, here I am comparing the physiological conditions of the groups that both received false feedback, but of two different kinds.

In the Attraction Study, I collected the heart rate and respiration data and grouped them into the slow and fast breathing feedback conditions. I did not observe a statistical difference between the two conditions in terms of heart rate (Average: p=0.42, SD: p=0.06) nor respiration rate (Average: p=0.56, SD: p=0.26). The graphs of the real heart rate, real breathing rate and false breathing rate feedback from the audio are attached in Appendix I.

In the Stress Study, our plots of the heart rate and respiration data did not show significant differences between the conditions either. The graphs of the real heart rate, real breathing rate during both fast/slow feedback section are attached in Appendix I.

The results indicate that the variations in false respiration feedback in our system did not cause corresponding physical changes. Thus, I see the behavioral changes as the results of a cognitive process that occurred when the participants received false body signals from external stimuli.

5.3.3.3 Cognitive changes during false feedback

Stress Study (SS)

To examine the effects of our intervention on anxiety, I compared the two sets of data from the STAI tests collected before and after the GRE test.

Fig.5.8 shows the boxplot that indicates how the anxiety scores changed in comparison with the person's baseline level in each feedback condition.

Here are the changed scores of each participant:

Fast breathing sound group: 1, 2, 6, 10, 13, 24, 35, 52
Slow breathing sound group: -11, -1, 1, 1, 6, 6, 8, 14

Additionally, a paired t-test revealed the statistically significant difference (p = .048) in terms of the changes in anxiety between the groups who heard two different rates of breathing, though the p value is close to 0.05. Also, in the fast breathing sound group, the standard deviation is much higher (SD = 18.0) than in the slow breathing sound group (SD = 7.41).

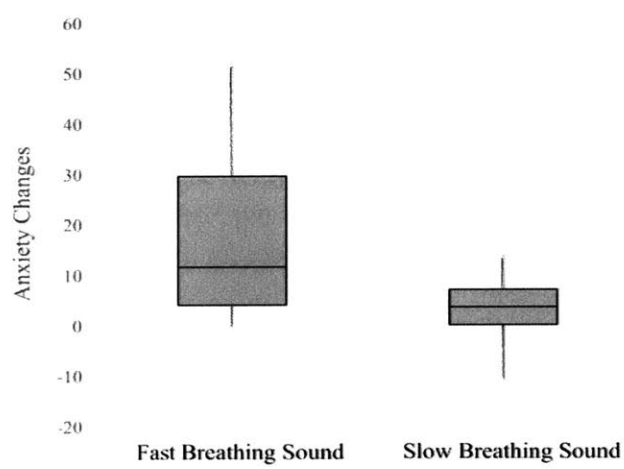

Fig. 5.10 Boxplot showing the change in anxiety (post GRE test - pre GRE test) in both conditions

Without being aware of the feedback changes, the participants reported different perceptual experiences for the two tests that match with the two breathing conditions. In particular, all four participants who experienced fast breathing feedback initially reported the first test as harder than the second one. However, the participants who experienced the slow breathing feedback did not initially express a bias about the difficulty of the two tests.

In the fast breathing feedback condition:

" (The breathing sound in) *the second part cuts off my breath. I might end up breathing too fast.*" (S5)
"*At the first, I felt much more nervous. Maybe the first test was hard.*" (S4)
"*The first study is way harder*" (S7)

In the slow breathing feedback condition:
"*In the second test, I breathed more relaxed.*" (S7)
"*The two tests are both hard in different ways.*" (S8)

Attraction Study (AS)

Table 2 shows the mean and standard deviation for the attractiveness ratings of the pictures for which the participants heard the short respiration feedback and the pictures for which they heard the long respiration feedback.

	fast and loud respiration sound	*slow and light* respiration sound
Attractive	3.15 (1.59)	3.70 (1.65)
Friendly	3.31 (1.72)	3.48 (1.63)
Exciting	3.88 (1.51)	3.42 (1.59)
Kiss	4.43 (2.39)	4.10 (2.14)
Date	4.42 (1.69)	4.75 (1.56)

Table.2 Descriptive statistics summarizing ratings in the Attraction Study: Average and Standard Deviation. (0 as "Very Much", 10 as "Not at all")

The paired t-tests revealed a significant difference in the rating for "Attractive" (p = 0.01) between the two groups. Specifically, test subjects who heard the fast respiration feedback rated women as more attractive. Lower ratings mean the participant thought the women in the pictures were more attractive. However, there are no significant differences observed for the ratings "Friendly" ($p > 0.09$), "Exciting" ($p > 0.28$) , "Kiss" ($p > 0.23$) and "Date"($p > 0.15$).

The results showed the misattribution of arousal effect only for physical attraction but not for other interpersonal attraction dimensions. The other dimensions of attraction, such as "friendly", "exciting", "want to kiss/date the other person" involve more than simple attraction phenomena including the reciprocity of liking effect, pratfall effect, matching hypothesis, similarity effect, and more (Montoya & Horton, 2014). Thus, it is expected to observe a lack of significant differences between the two groups of participants.

Several participants also talked about the effects of the respiration feedback on their emotional appraisal. One participant recalled the experience and mentioned: "*I am not breathing that fast, am I? Wait, she is not that hot.*" "*I tried to control my breath cause it was going too fast. Then I got a bit nervous.*" (A9) "*There is one picture, I feel my breathing is faster. Probably I like her?*" (A7)

5.4 Discussion of Masque studies

5.4.1 The disconnect between cognitive and physiological actions

One hypothesis was that the actual physiological data would be affected by the false feedback, thus the changed cognitive data could be due to actual physiological changes. However, we did not observe that the actual physiological data of the participants perform differently between the two false feedback conditions. Thus, *the behavioral and cognitive differences are not caused by the actual physiological experiences but rather by the mistaken information our participants received from the false feedback.* Several participants reported perceiving the mismatched breathing feedback "*Hearing my sound makes me feel agitated, even though I might not.*" (A4) "*I noticed myself breathing heavier when I looked at a picture that I am not very excited at.*" (A5) Also, 12 out of the 20 participants mentioned that they were not sure about whether the sound is their actual breathing, though they also admit the experience of hearing their own respiration is very unfamiliar in itself. When there was a delay in the system or a mismatch, the participants tended to consider it as a glitch in the recording.

The disconnect between physiological and cognitive experiences in everyday life is often perceived as a disadvantage because of its implication of the lack of self-awareness (Goodwin, et al., 2006), (Teeters, El Kaliouby, & Picard, 2006). However, I see an opportunity to use this disconnect to "mislead" people with false body signals to achieve a desired affective state. Similar to calming down with slow breathing sounds, I can help people get excited with fast, loud breathing sounds. Notably, the effect of false feedback went beyond self-perceived states such as calmness and stress level, but also induced high-level cognitive responses. In our case, the difficulty of a test and the physical attractiveness of individuals were both influenced by the misrepresented body signal.

5.4.2 Attention to the intervention

Though the presence of respiration sound was obvious at the beginning, most participants reported that they tuned the respiration sound out later on, especially during the test and picture rating tasks. "*I think focusing on the reading made me forget about the respiration.*" (S3) "*I kinda ignored it once I need to answer questions.*" (A2) These results indicate that even when in the periphery of people's attention, the respiration sound was effective: slow/light and fast/loud respiration sounds led to different biases.

An interesting observation is that 6 out of 20 participants mentioned that purely hearing their own breathing already made them pay more attention to their internal states at the onset of the experiment. The corresponding emotional responses are based on the situations the participants are in, feeling more nervous (in the Stress study) and more self-conscious (in the Attraction study), respectively. I envision that effective interventions to a certain extent could be achieved simply by turning the volume up and down the user's actual interoceptive signals. For example, we could provide real-time amplified feedback of heart rate and respiration rate as an alarm for drinkers (Ryan & Howes, 2002) and smokers (Jones R. A., 1987), or simply to help people be more connected with themselves, such as in case of aging (Khalsa, Rudrauf, & Tranel, 2009).

5.4.3 Design implication and application

Implicit and flexible feedback

Throughout the studies it was clear that the interoceptive feedback does not need explicit attention from the users, especially when they were concentrated on their tasks. This provides a unique opportunity for designing real-time interventions, similar to calm technology (Wongsuphasawat, Gamburg, & Moraveji, 2012), that do not distract the user (Adams, Costa, Jung, & Choudhury, 2015) or cause extra stress (MacLean, Roseway, & Czerwinski, 2013). At the same time, I envision a flexible use of interoceptive feedback, which automatically adapts the signals (Ghandeharioun & Picard, 2017). The biofeedback signal does not need to be veritable all the time. The feedback can slow down or race up based on the current state of the user and the desired state. This way, the user does not necessarily know when the feedback is false or real, but the cognitive behaviors and emotional states are still being influenced (Olsson & Öhman, 2009).

From intervention to learning

A strong benefit of respiration interventions is that the user could learn to apply the technique directly themselves. Breathing is the only interoceptive experience that people can control, easily and voluntarily. I see the use of Masque not as the ultimate solution for emotion regulation but a pathway for the user to understand their capacity to control affective states with bodily actions. If the user could be influenced by a false signal, they can also consciously breathe more slowly during a stressful event.

Aware of the context

Though users all received the false respiratory feedback as purely fast (25bpm) or slow (12bpm), their biases in cognitive experience were different between the two studies, namely difficulty of the test and physical attractiveness. While designing interventions, it is important to keep in mind that the user might need different stimuli throughout the day. A calming effect is the most useful. Strategically exposing the users to intense body experiences and stressful situations could be used in long-term treatment for illnesses such as panic disorder (Craske, Rowe, Lewin, & Noriega-Dimitri, Interoceptive exposure versus breathing retraining within cognitive-behavioural therapy for panic disorder with agoraphobil, 1997). Also, amplifying the interoceptive signals could help patients with self-recognition deficits (Frassinetti, Maini, Romualdi, Galante, & Avanzi, 2008).

6. Conclusion

6.1 Summary

This thesis explored the sense of self and its interventions through sensorial and perceptual experiences. These are the concrete contributions of this thesis:

- It extracted a theoretical framework of self-perception from the domains of physiology, psychology and neuroscience. In the review, a collection of proven methods and standard experiments for measuring self awareness and inducing perceptual changes are listed. These existing mechanisms and previous work laid the foundation and guided the design of the two built projects in this thesis.

- The thesis presents Tree and TreeSense, two VR sensory experiences that utilizes exteroceptive signals to induce a body ownership illusion. The two physical experiences were realized with EMS and with a multi-sensory installation that involves vibration, scent and heat. We also achieved a high-production quality deployment of the experience in film festivals where so far almost 1000 audience members had the chance to experience the project.

- The thesis presents Masque, a psychoacoustic device that manipulates respiration sound, in which physiological sensing and non-intrusive, systematic interoceptive interventions are integrated. The system is fully realized with the design of electronics, product design, 3D fabrication and signal processing.

- Lastly, the thesis presents two cognitive studies around the bias in behavioral and cognitive experiences caused by Masque.

6.2 Conclusion

Inward to Outward is an attempt to understand one's relationship to *herself*, originating from my own life, to the discursive questions about pain and pleasure of the body, about gymnastics and junk food, about desire and repulsion we hold to. In the background chapter, I tried to take a glimpse of the biological, physiological root of human self perception. Later in Chapter 3, I emphasized the necessity of considering biological evidence and physiological experience in the examination of social and cultural constructions. These two chapters foresee the objectives and methodology in my practice: scientific evidences and data as the ground, engineering construction as the methods, in the pursuit of a personal and philosophical inquiry - *how do we perceive ourselves?*

Our making of our worlds is brutally present and active in our conceptualizations and makings of self. To me, the accuracy and programmability of manipulating body experience and human affect ought to exist with the ambiguity and ineffability in the desire of doing so. Therefore, I keep asking myself to pay very close and critical attention to what it is that is being made. At very basics of this thesis, it simply suggests that we pay attention to the fear, desire, ambition, and clinging that motivate the building of self identity. As the defective self is confronted, it then reminds us of the malleability of self and the unnecessity of grasping.

6.3 Future work

6.3.1 Masque

So far I focused on bias caused by different examples of false respiratory feedback. I plan to add two control groups (without any audio feedback, with the real respiratory feedback) in a future study, so as to understand the effects of the presence of amplified respiration sound. Though there are theories indicating that behaviors can be influenced unconsciously by stimuli (Weiser & Brown, 1997), further experiments are needed to examine whether the feedback would still be effective when the user is fully aware that the signal might be not accurate. There is also the interest in studying whether there would be differences between female and male subjects in the Attraction Study.

6.3.2 Being a tree

So far *Tree* has been and is going to be internationally exhibited in various film festivals and other venues. For the next step, I am focusing on the development of TreeSense. We will be presenting a room scale installation of TreeSense in Shanghai from September to October in 2017. TreeSense is also commissioned to be permanently exhibited in Lusto - The Finnish Forest Museum, which is located in a suburb area of Savonlinna city, one of the national sceneries of Finland. We will adapt the virtual terrace inside TreeSense to the local landscape of Savonlinna. The project will be featured as their first VR experience to connect kids and teachers to the local forest environment.

6.3.2 Capture a sense of self

Throughout the journey of this thesis, I kept investigating the reconstitution of perceptions and experiences related to oneself, which inevitably is also a process of introspection and self-confrontation. As an artist in practice, I see the knowledge of this thesis permeate my on-going work, affecting every part of it. On the one hand, I affirm the malleability of the self in the arguments of academic thesis and science studies. On the other hand, I capture the renewals and narrations of the self, of our only protagonist in life, in the subjective, transformative, participatory experiences of art.

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Appendix I: User data in Attraction Study and Stress Study

Attraction Study:
Each graph plots the real heart rate and breathing rate of the participant as well as the fake breathing rate heard from the audio feedback. The two vertical lines indicate the beginning and the end of the photo view section in the study.

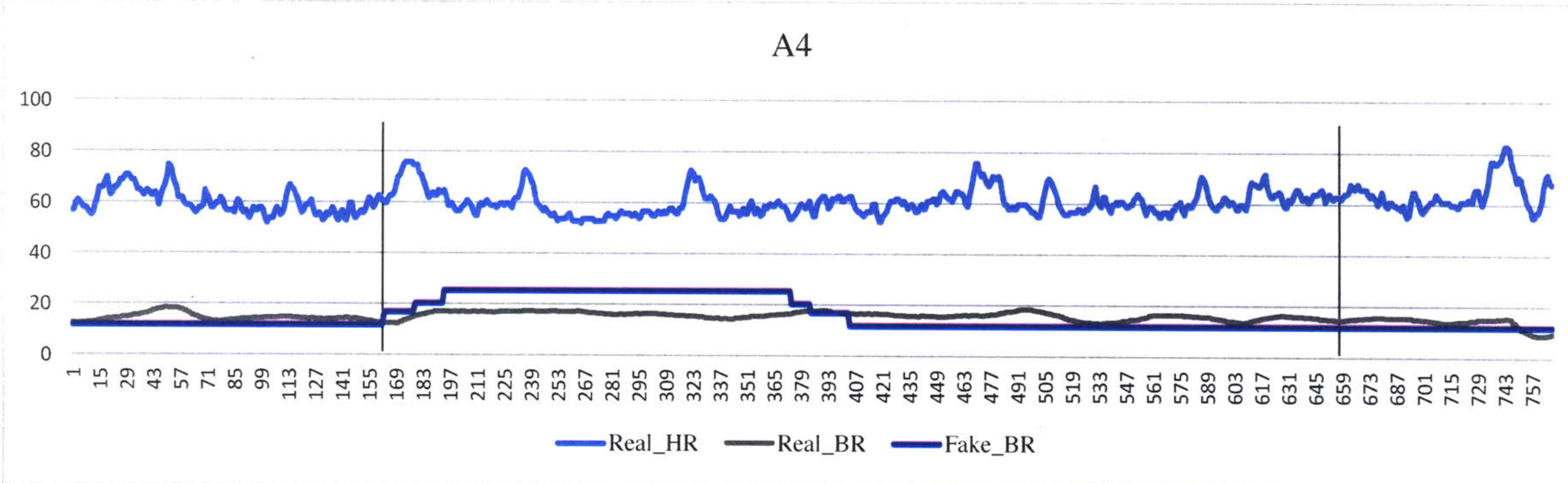
There are only complete data for 9 participants in the Attraction Study because the bioHarness was not secured during the experiment for participants A2 and A3 in the slow-fast group and A7 in the fast-slow group. The fast breathing sound feedback is at 25 bpm and slow breathing sound feedback is at 12 bpm.

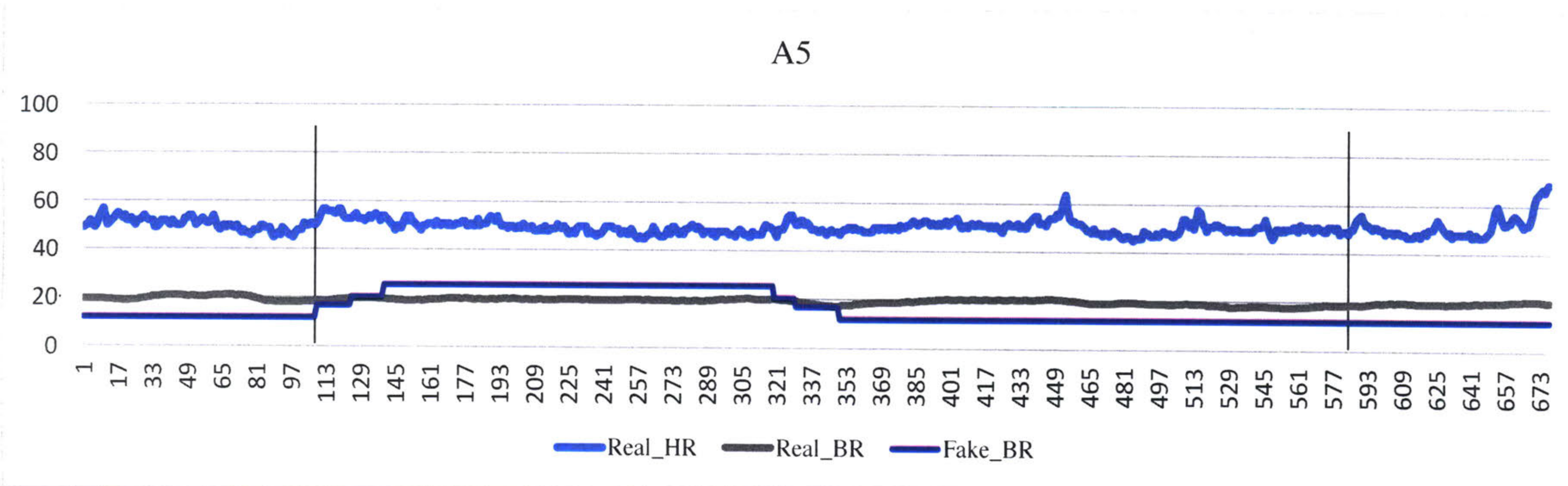
Stress Study:

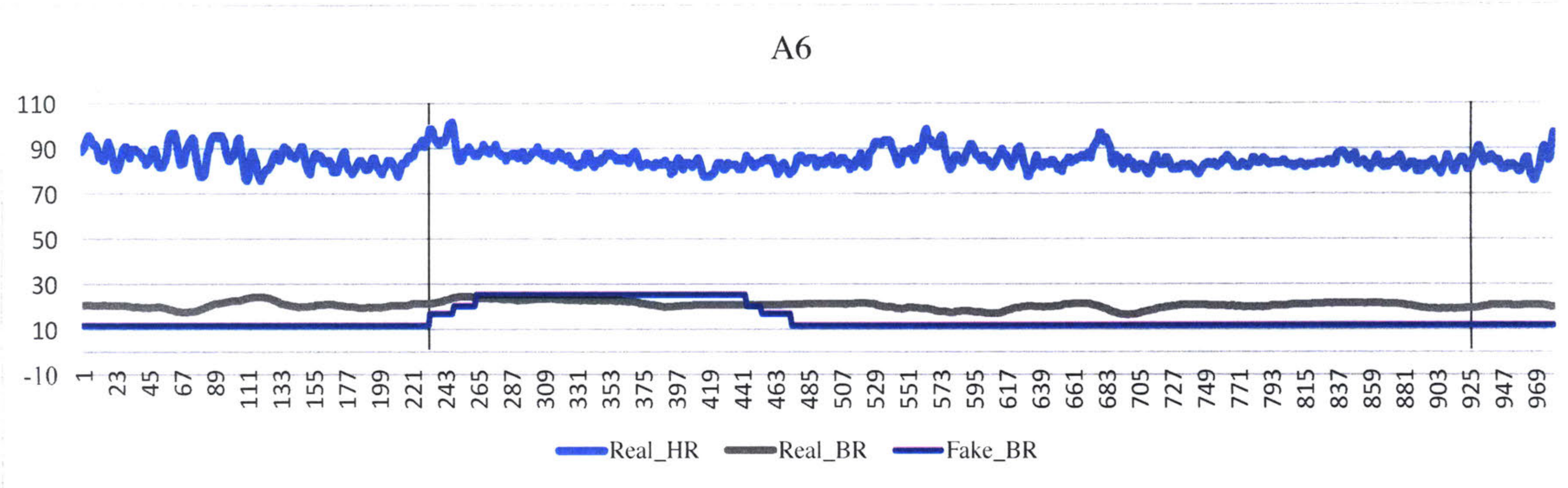
The graph shows the real heart rate and breathing rate of the participant during the fast breathing sound feedback (25 bpm) and slow breathing sound feedback (12 bpm).

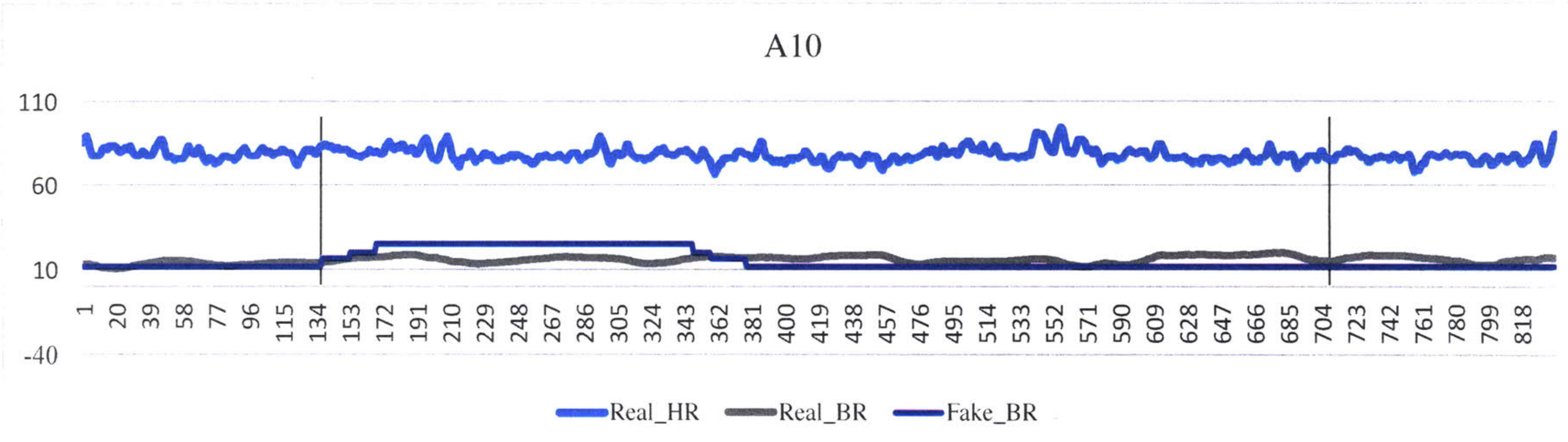
There are only complete data for 6 participants in the Stress Study because the bioHarness was not secured during the experiment for participant S3 and the experimenter forgot to record the data during the experiment for participant S5.

Fast - slow group in Attraction Study:






A6
110
90
70
50
30
10
-10
1
23
45
67
89
111
133
155
177
199
221
243
265
287
309
331
353
375
397
419
441
463
485
507
529
551
573
595
617
639
661
683
705
727
749
771
793
815
837
859
881
903
925
947
969
Real_HR
Real_BR
Fake_BR


A10
110
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-40
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39
58
77
96
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134
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172
191
210
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248
267
286
305
324
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362
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438
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495
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533
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723
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761
780
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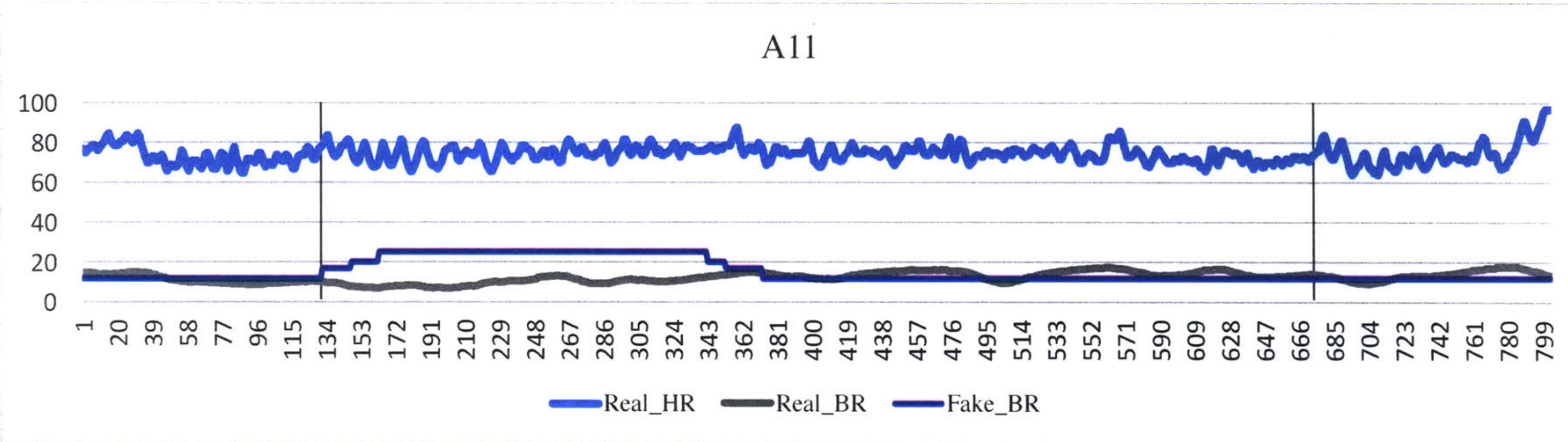
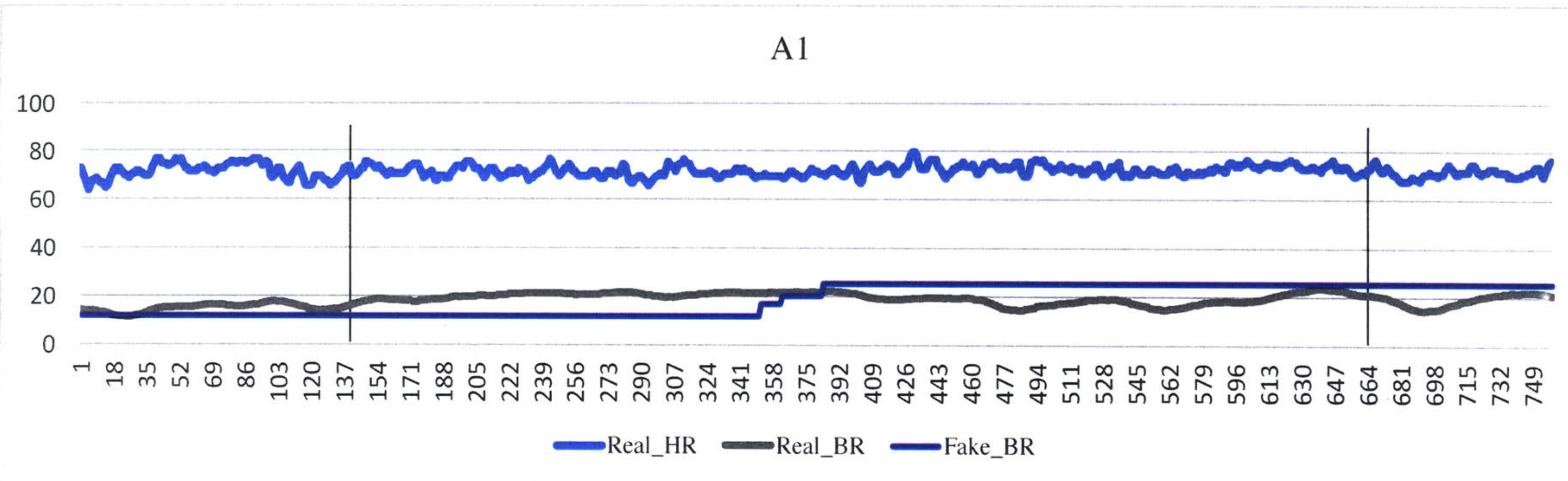
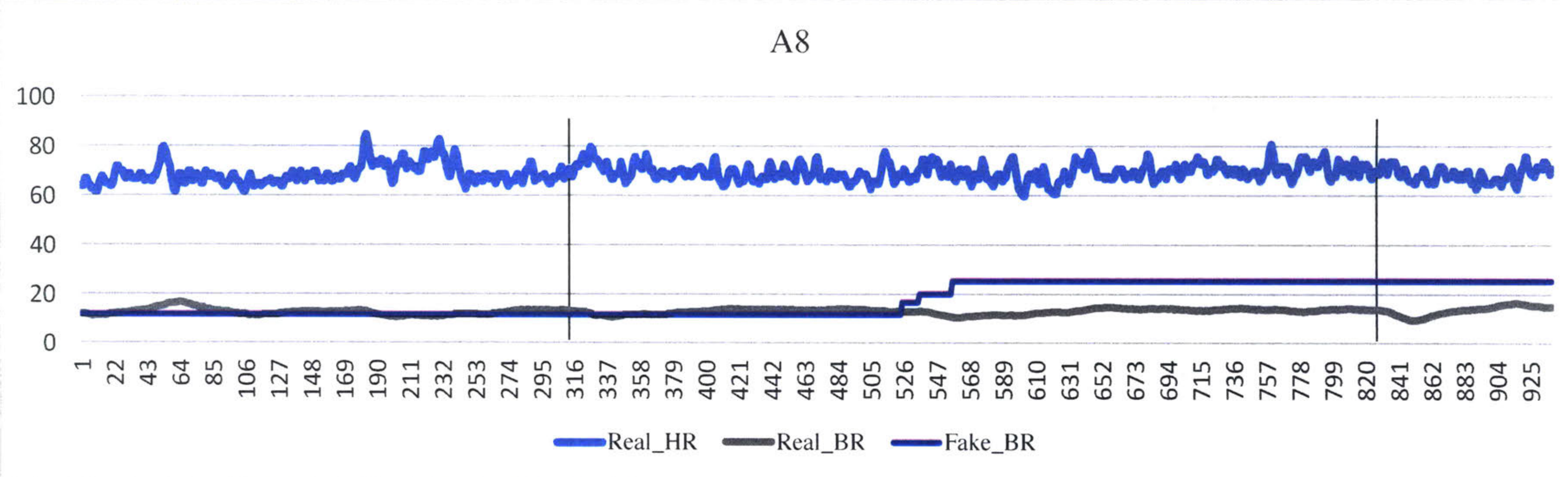
Real_HR
Real_BR
Fake_BR



Slow - fast group in Attraction Study:

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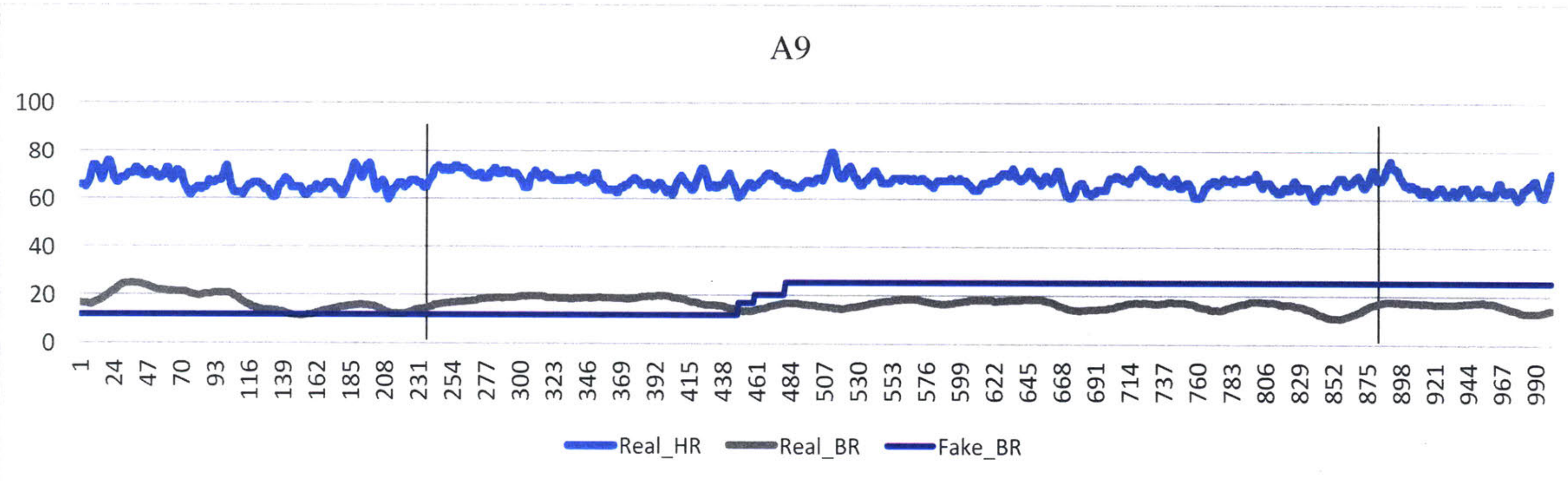
Real_HR
Real_BR
Fake_BR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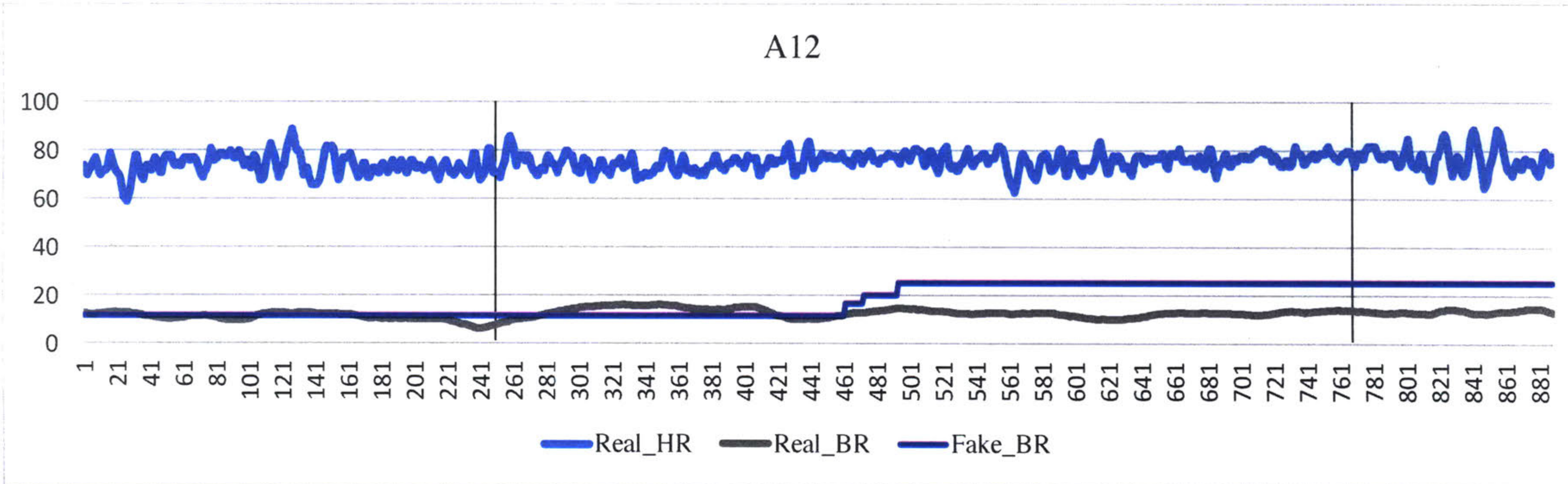
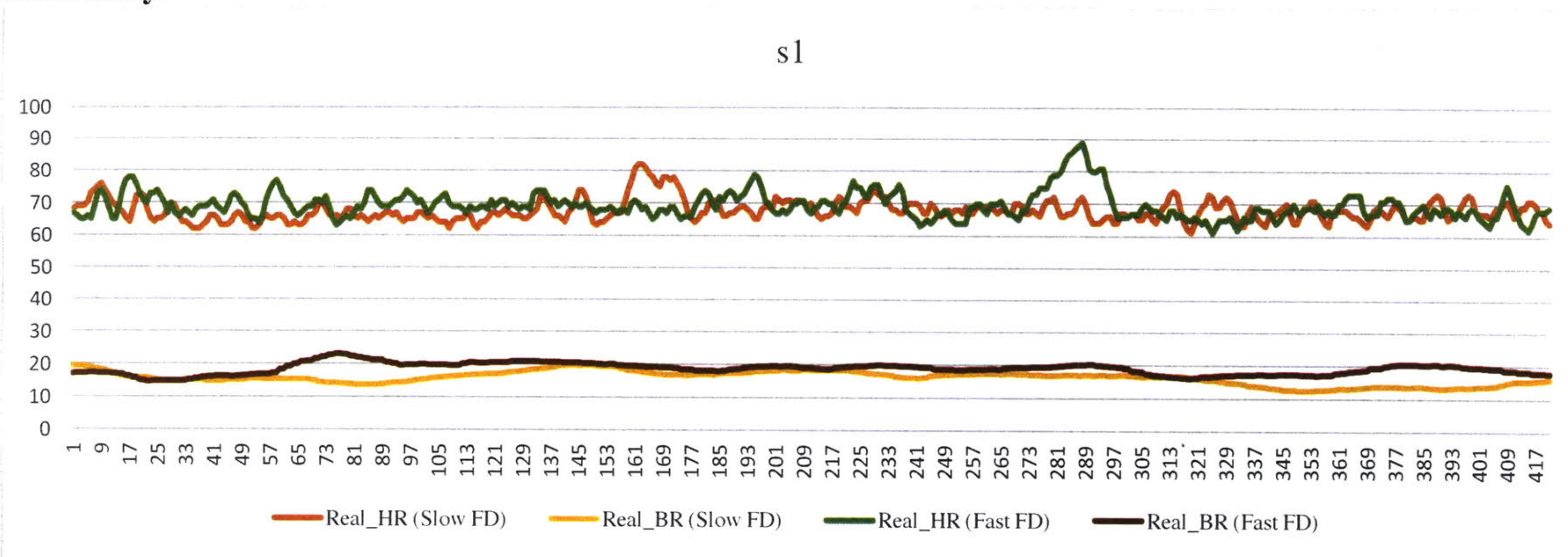
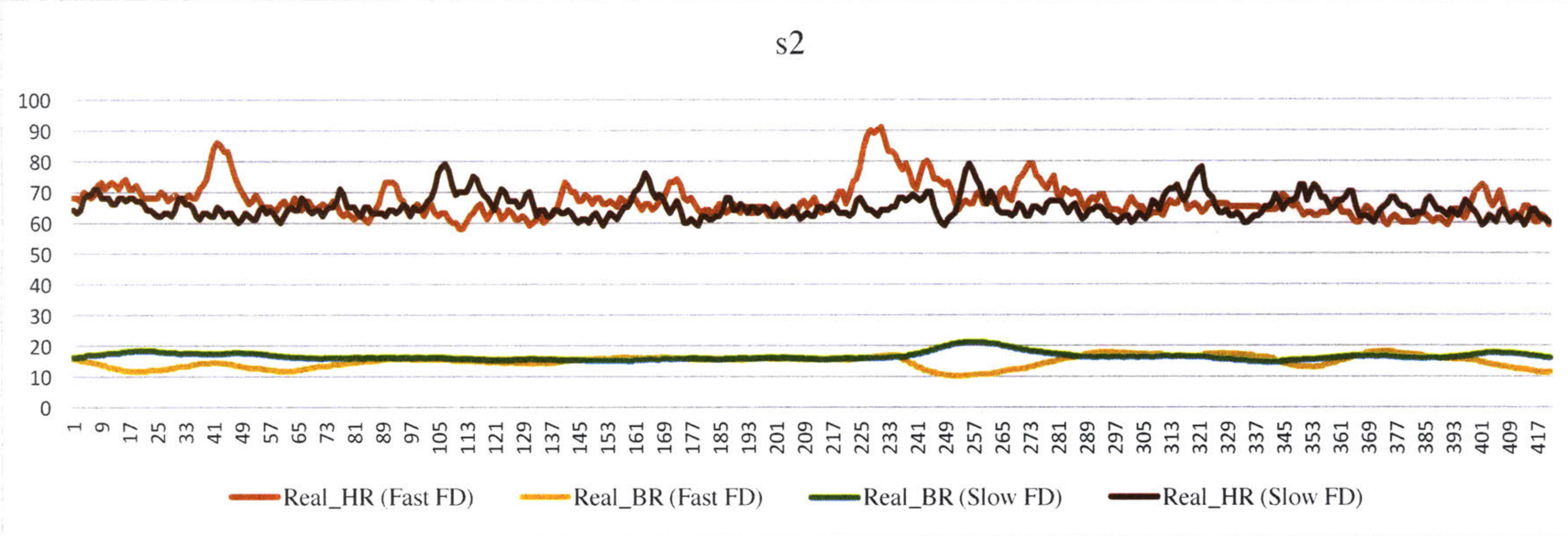
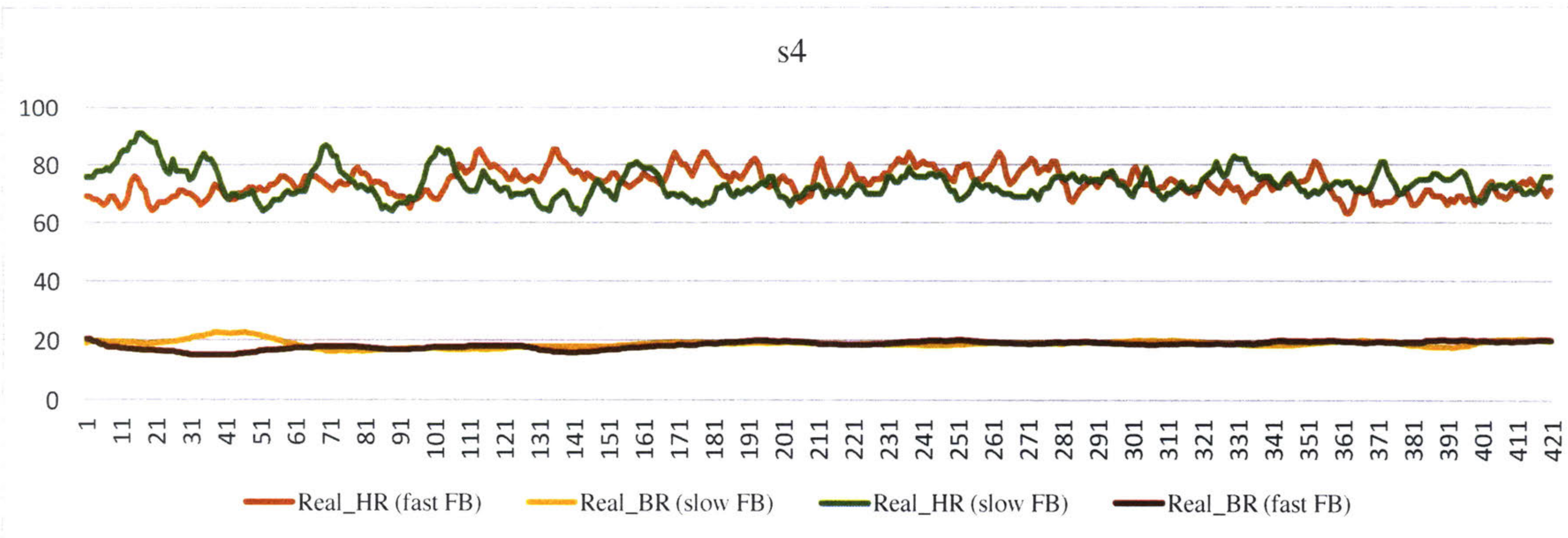
Real_HR
Real_BR
Fake_BR

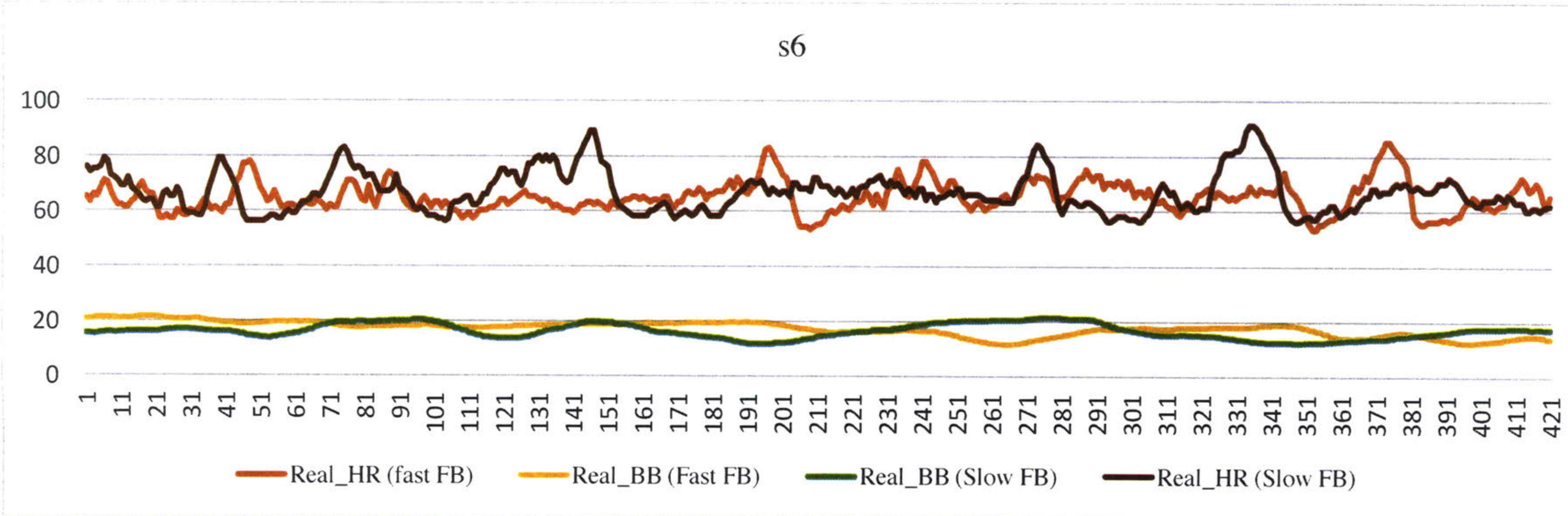


Stress Study:




s2
Real_HR (Fast FD)
Real_BR (Fast FD)
Real_BR (Slow FD)
Real_HR (Slow FD)


s4
Real_HR (fast FB)
Real_BR (slow FB)
Real_HR (slow FB)
Real_BR (fast FB)


s6
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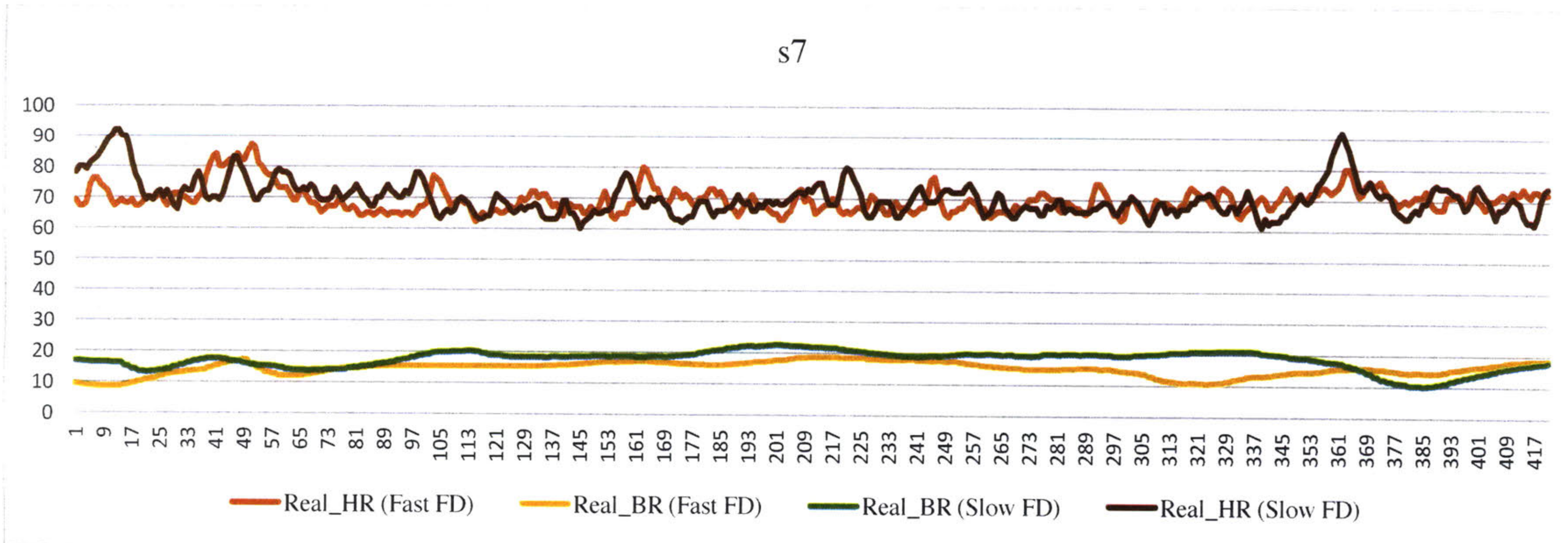
40
20
0
Real_HR (fast FB)
Real_BB (Fast FB)
Real_BB (Slow FB)
Real_HR (Slow FB)


s7
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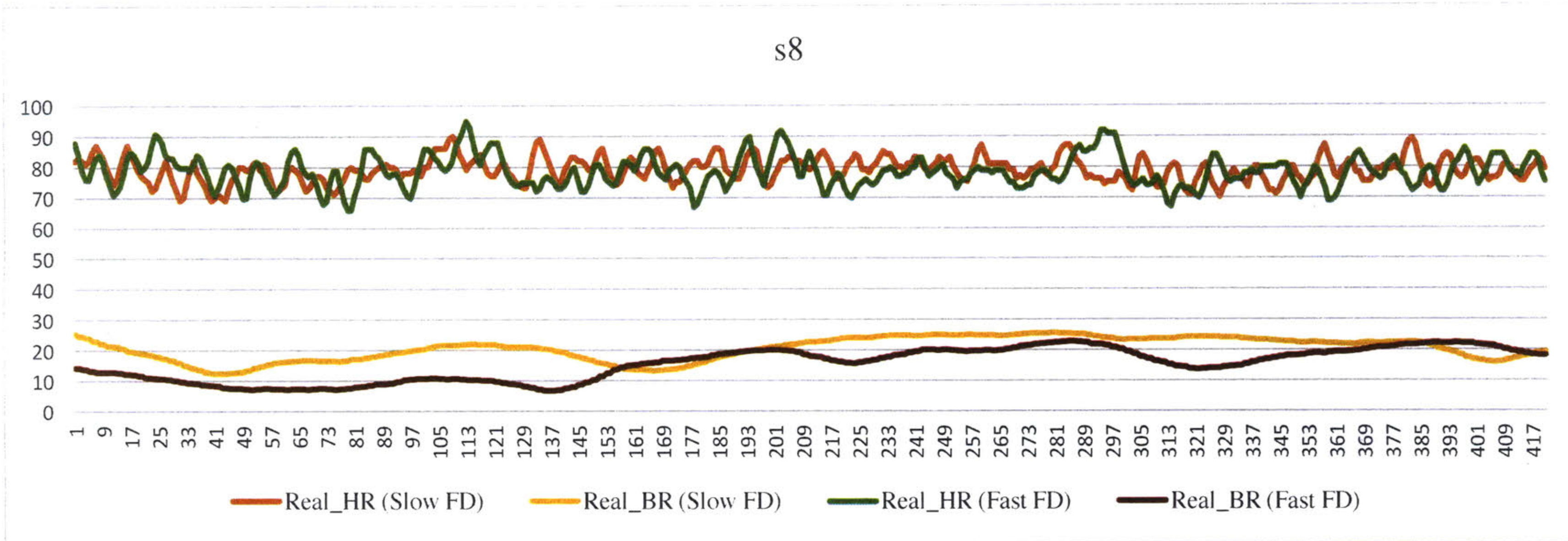
Real_HR (Fast FD)
Real_BR (Fast FD)
Real_BR (Slow FD)
Real_HR (Slow FD)


s8
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1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145 153 161 169 177 185 193 201 209 217 225 233 241 249 257 265 273 281 289 297 305 313 321 329 337 345 353 361 369 377 385 393 401 409 417
Real_HR (Slow FD)
Real_BR (Slow FD)
Real_HR (Fast FD)
Real_BR (Fast FD)

Appendix II: TAS scores of the 20 participants