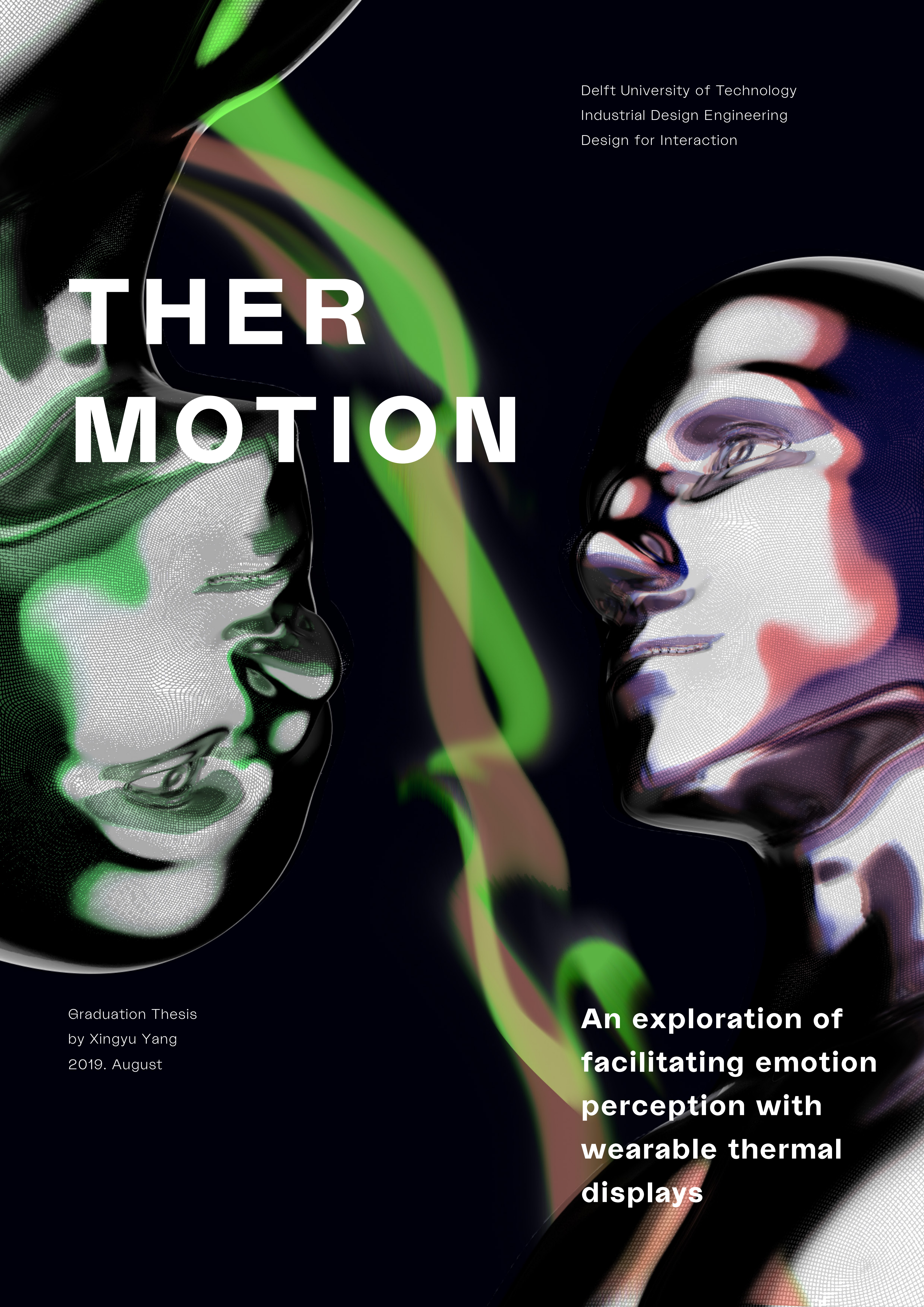
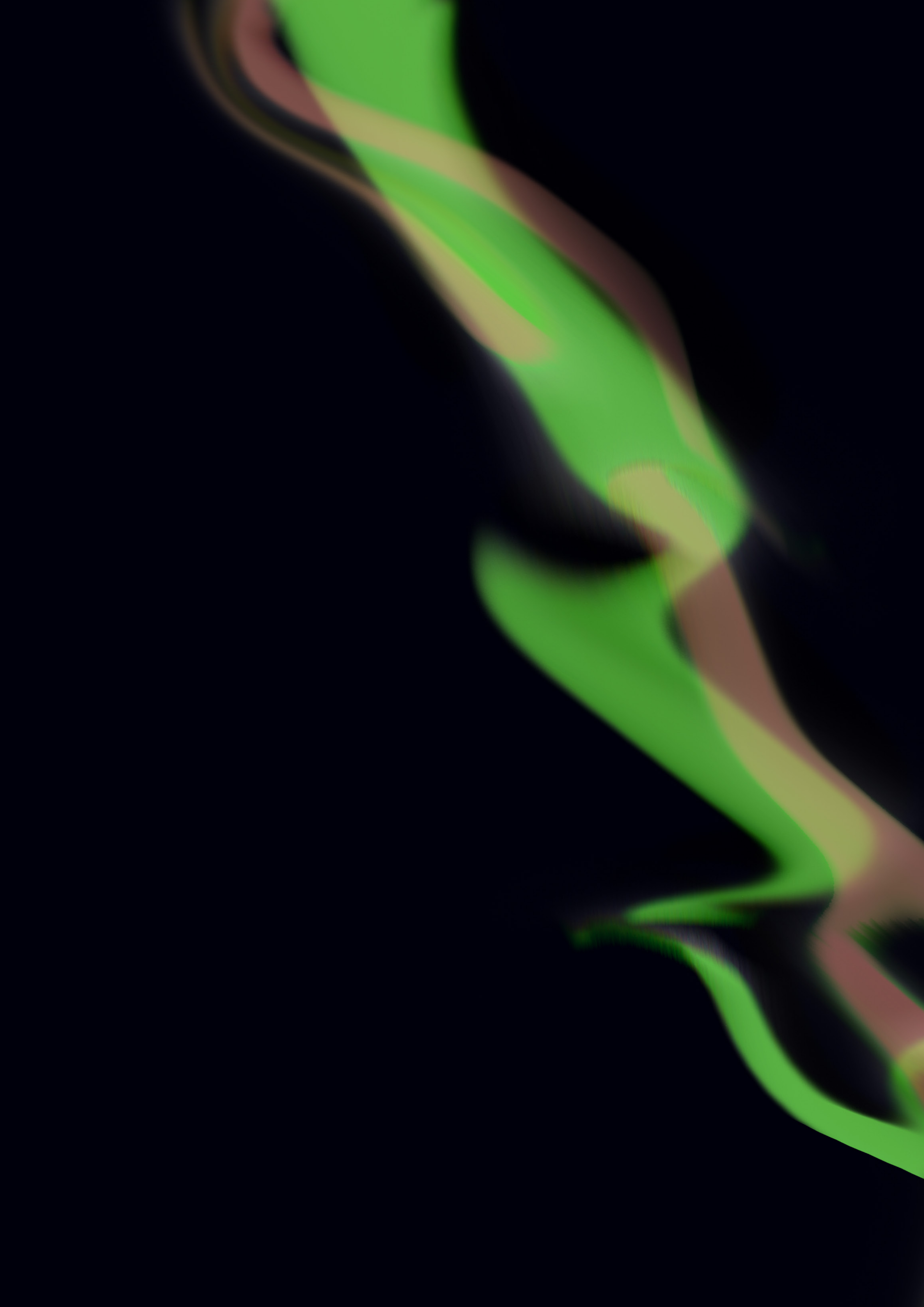


Delft University of Technology
Industrial Design Engineering
Design for Interaction

THER MOTION

Graduation Thesis
by Xingyu Yang
2019. August

An exploration of facilitating emotion perception with wearable thermal displays



Thermotion : An exploration of facilitating emotion perception with wearable thermal displays

Master graduation thesis
by Xingyu Yang
2019. August

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Preface

This thesis is the final deliverable of the master graduation program Design for Interaction. It reports the process and outcome of a research project - Thermotion: An exploration of facilitating emotion perception with wearable thermal display. Centrum Wiskunde & Informatica (CWI), who offers the assignment, is another party of the project. The starting point of this project is the assignment from CWI: How to visualize biometric data through wearables to contribute to multi-party communication. Wearables and tangible interactions are two aspects expected to be studied within the given topic.

Graduating seems like a lonely journey. But I always know I'm not alone. I would like to thank my supervisor team for the supporting and guiding throughout the process. Kasper, Jessica and Abdallah, I feel fortunate to have you as my supervisors. Thank you Kasper for settling me in the Material Lab and helping me get access to the support from both fabrication and electronic areas. Your practical suggestions also keep pushing the project forward. Jess, thank you so much for being supportive whenever I need help. From helping clarify the direction to calling for EU emotion stimulus, or even looking for a room with air conditioner, your help comes from every aspect. I always feel motivated after talking with you. Abdallah, special thanks to you for the patient and careful guiding, inspiring and help. I really appreciate the resources you offered and the countless time and effort you spent with me on the project. The discussion or even argument with you really shapes the project into a qualified work, and led me inside the door of research.

I would also like to thank Jack and Thomas from the Distributed and Interactive Systems (DIS) group of CWI. Your work on the Iotsa board and the application makes the experiment and data analysis much professional and easier. Thanks to Linda and Martin from the Material Lab of Industrial Design Engineering Faculty. Linda's teaching on fabrication and Martin's instruction and help on electronics make this interdisciplinary project possible to proceed. Besides, thanks to Pablo and Jie, your suggestions and support also help me a lot . For all the participants involved in this project, I appreciate your time and effort. The project can't be finished without you. Special thanks to all the fellows who worked together during the process. Your company, cheering up and selfless help is an important force driving the project moving forward. Xiaomin, I appreciate your help from picking the clothes for prototyping to offering inspirations for the report's visual. Guo and Shuai, the talks with you about design and scientific research are really helpful for me to continue during those lost days. Finally, I would like to thank my dear dear parents for being there with me all the time and offering advise for the troubles I encountered. You are the source of my courage, enabling me to face difficulties along the way. Reaching the destination of the journey, the joy is not only mine, but also shared with you all.

Abstract

The project aims at exploring tangible ways to communicate emotion. To narrow down the scope, I lay the focus on emotion communication in remote settings, a context when nonverbal communication is usually limited. From interviews, the neutral expression is found to be the main factor hindering a sufficient understanding of others' emotional state. Therefore, the scope is narrowed down to a topic related to the real-world problem: **Contributing to the emotion interpretation from the neutral verbal expression.**

While verbal communication cannot convey emotion sufficiently, tangible modalities like haptics, thermal feedback are promising extra channels to explore. Communicating affection with the physical stimulus is not only supported by theoretical studies like embodying emotion theory but also practiced through prototyping and experimenting from HCI filed. Within this project, thermal stimulus, a modality highly related to emotional experience without causing privacy issue, is selected for the study. Thus, the research can be further framed as: **How thermal stimulus contribute to emotion interpretation from the neutral verbal expression?** Considering the application perspective and the requirement about wearables from CWI, the thermal stimulus should be designed as wearables. The research is conducted in the path of the controlled experiment to generate solid findings. Voice message, a medium less explored in the area of remote communication, is chosen as the case for study. Therefore, the final research question is formulated as follows: **How can wearable thermal display contribute to emotion interpretation from the neutrally spoken voice messages?**

The project follows the path of research through design. First, through literature review and quick user test, a pre-study leads to some initial decisions for the experiment: 1) using the upper chest as the body location. 2) using woven silk as the contact medium. 3) setting four thermal stimuli (high intensity warm 38°C, low intensity warm 35°C, high intensity cold 26°C, low intensity cold 29°C).

Afterward, the first experiment is conducted to find the recognizable and acceptable on-body thermal stimulus with a suitable contact medium (skin or fabric) for the second experiment. The study with 12 participants collects the ratings in terms of subjective intensity and comfort. The findings indicate that low intensities cannot be used if the thermal stimuli should be detectable for most people. For the cool stimuli, the intensity is decreased from -6°C to -4°C to ensure participant comfort. Besides, the fabric is not used for the second experiment because of its delay effect on thermal sensation.

Between the two experiments, a study is conducted to validate that the neutral tone can make a normal voice message perceived more neutral. Twelve

neutrally spoken voice stimuli are generated by an AI voice generator and compared with the original normally spoken voices (from a validated database) in terms of valence and arousal. The result shows that the neutral expression does make a sentence with either positive or negative content perceived more neutral.

The second experiment is to explore how thermal stimulus can affect emotion perception from nuetrally spoken voice messages. Participants listen to eight voice messages and experience the thermal stimuli at the same time. Afterward, they give their ratings in terms of valence and arousal from the voice messages. Each voice message is paired with three thermal conditions (warm, cold, baseline). The result shows that warm stimulus augments the perceived positiveness of positive messages while cold stimulus augments the negativeness of negative messages.

However, augmenting the emotion perception doesn't necessarily mean the accuracy of emotion perception. The contribution and limitation of the project are discussed in the end.

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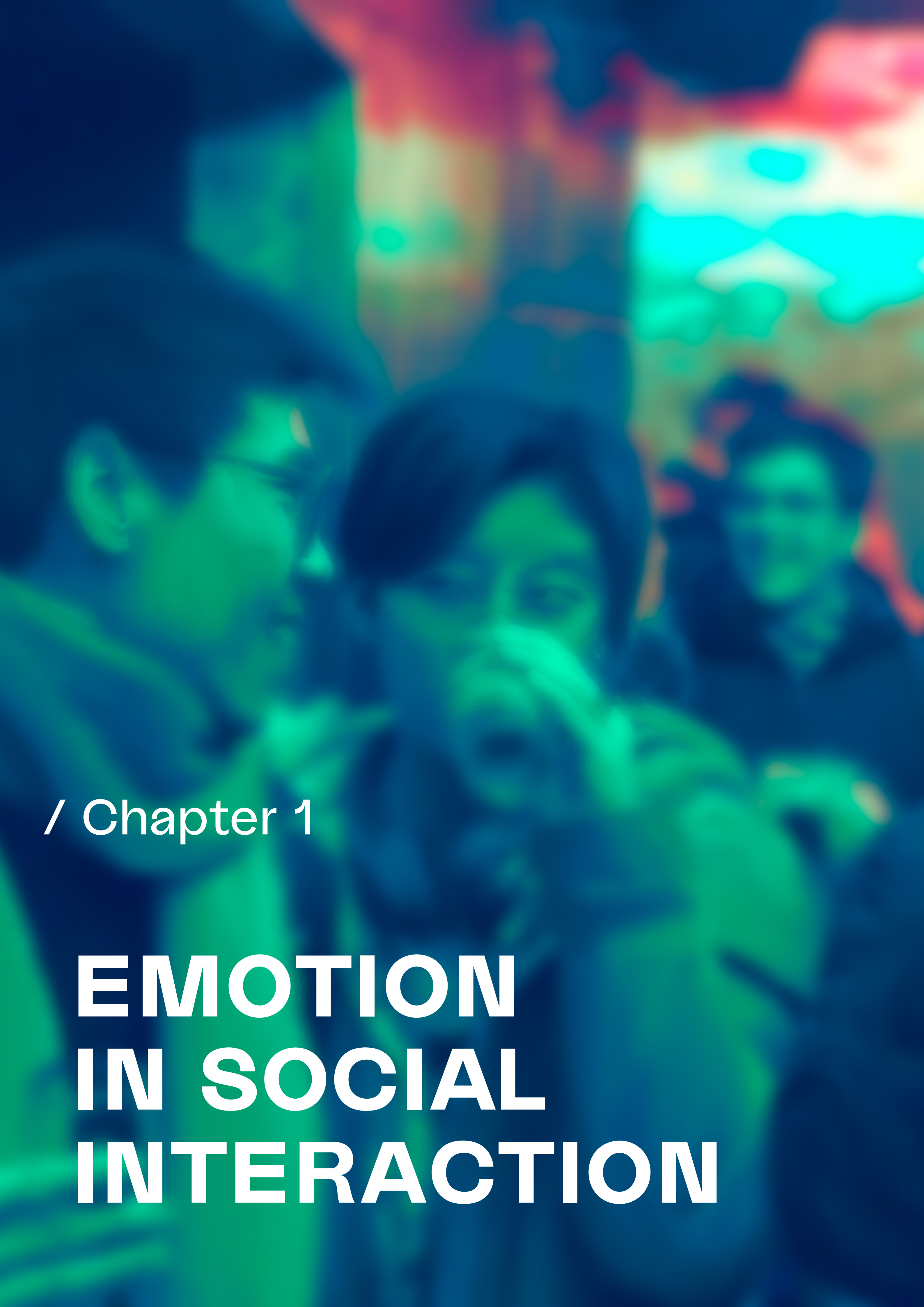


/ Chapter 1

EMOTION IN SOCIAL INTERACTION

Introduction

Emotion coordinates human behavior and psychological states [1]. It is an important clue in social interaction that helps people to infer others' conditions. Based on the perceived condition, a person can give proper feedback accordingly. For example, a person might comfort his or her friend when sensing negative emotions during a conversation. Thus, emotion communication is crucial to increase people's empathy and social connections. This chapter lays the focus on remote communication - a typical scenario when emotion can't be communicated sufficiently. To probe the problem further, interview about emotion interpretation issues is conducted. The result is used to indicate the research direction on contributing emotion communication in remote settings. The chapter ends with a brief introduction of emotion models.

1.1 Insufficient emotion communication

Communication is a process of sharing and receiving information, thoughts, and emotions. However, people can't always communicate emotion sufficiently. Many obstacles (e.g. autism, remote communication or hiding emotion on purpose) hinder emotion convey. In those cases, people lack the clues or the abilities to interpret others' feelings.

Remote communication

Remote communication (text message, voice message, audio call, etc.) is a typical case of insufficient communication. As shown in Figure 1, human's daily communication usually consists of two main parts: verbal communication and nonverbal communication [2].

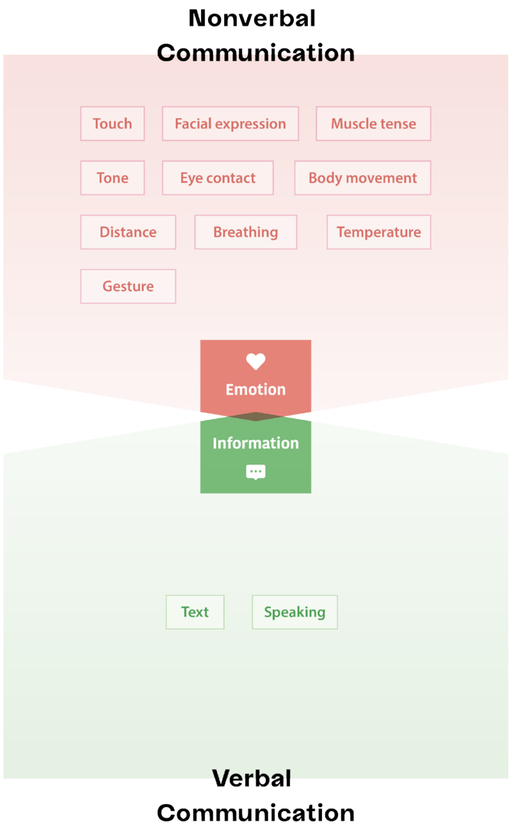


Figure 1. verbal communication vs nonverbal communication

While verbal communication normally contains linguistic elements like text or speaking language, nonverbal communication involves more various forms (e.g., facial expression, gesture, touch). Between the two, verbal communication is usually for information exchange. Nonverbal communication is deeply connected to communicating thoughts and feelings [3]. During face to face settings, both verbal and nonverbal information is conveyed, which relatively offers sufficient cues for people to interpret others' emotional states. However, in remote communication, nonverbal information is usually not conveyed (text message) or partly conveyed (voice call). Therefore, people lack enough information to infer others' feelings, which might cause misunderstandings and weak connections with others.

Nuetral expression & ambiguous emotion interpretation

To get further insights from people's real life, I interviewed nine persons about their emotion perception issues when communicating remotely. A booklet (Figure 2) was made to record their experience.

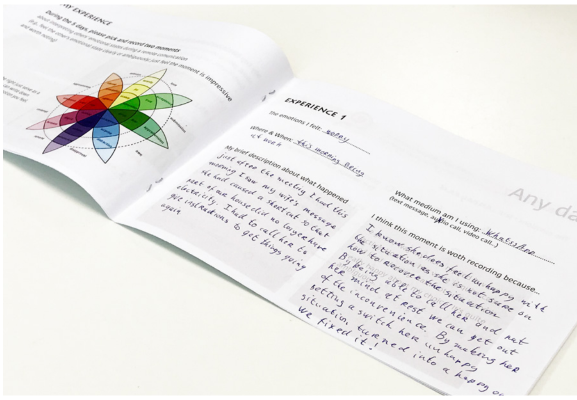


Figure 2. An example of the sensitizing booklet

The detailed information of the booklet can be found in Appendix. Nine participants were involved. They are students from TU Delft and researchers from CWI. In the booklet, they were asked to record their experience of having difficulty or feeling smooth interpreting others' emotional states during remote communication. The result of the interview is shown in Table 1.

Participant	Basic info.	Two experience in terms of emotion perception						
		medium	with whom, where, when	what are you talking about	what emotion do you sense	clear or ambiguous	what cues make it clear or ambiguous	effects on your feelings
P1	Thai, female	audio	mom, home, morning	recent condition, election	worry	clear	tone content context, there is an election and the person my mom is against has advantage and tend to run the government.	
		audio	friend, home, depends	recent condition, get fired	unsure	ambiguous	calm tone, serious content	
P2	Dutch, male	text	wife, work place	emergency, power cut	worry	clear	expression content	nervous
		audio	wife, work place	help her to solve the power cut	relief	clear	tone speaking speed	happy
P3	Indian, male	audio	brother, at home	recemt condition, complaining about motorcycle breaking down	frustration anger	clear	tone Volume content been through the same experience	frustrated and angry
		audio	friend, at home	recent condition, get some new offers	neutral	ambiguous	neutral tone	confused but it doesn't really bother me
P4	Chinese, male	audio	friend working on a same project, home	discuss about the design work	anger	clear	speaking speed rhythm context, we have a divergence about the project	feel frustrated because we didn't communicate well
		audio	friend	making fun with friends	joy	clear	tone	happy, amused
P5	Chinese, female	text	teacher, at home	asking for help in a unproper way	anger	ambiguous (about degree)	expression content	worried
		text	friend, on the train to work	his interview is not going well	disappointment frustration	clear	expression content	sorry for him
P6	Chinese, male	text	co-worker, office, afternoon	experiment data is not good	unsure	ambiguous	expression content	frustrated (don't know if it's serious)
		text	co-author, home, after work	paper is submitted	unsure	ambiguous	expression content	doesn't affect me
P7	Chinese, female	audio	boyfriend, home	discuss about her design work	helpless	clear	sigh tone	upset annoyed
		audio	best friend	parents have a big quarrel	helpless sad	clear But ambiguous about the degree	sad tone way of expression speaking speed	sorry for her helpless
P8	Chinese, male	text	friend	invite his friend to eat out together	unsure	ambiguous	expression content (too short)	confused
P9	Chinese, male	text	friend, home	ask about graduation project progress	stressed upset	clear	content reply immediately (don't mention it)	I know her feeling since I'm going through the same thing
		video call	mom, home	my difficulty of finding a mentor	worried	clear	facial expression tone	makes me even more nervous

Figure 2. Interview results about what hinders emotion interpretation

Six out of the nine participants talked about the experience when they felt ambiguous to sense others' emotional states. They (P1, P3, P5, P6, P7, P8) all mentioned that the mismatching between the expression (way of using words, the structure of the sentences, tone, speaking speed, etc.) and the content made the interpretation difficult. Seven people talked about the experience when they felt others' emotion was clearly conveyed. In those cases, most people mentioned that there was a consistency between the content and the expression. If it's an audio conversation, then the content combined with the fitting expression like tone, speaking speed contributes to the clear emotion perception. If it's a text message, the various expressions like stickers or the suitable length of the reply also contributes to emotion interpretation.

1.2 Problem framing

In summary, the content of the message and the expression together affect emotion interpretation. Figure 3 illustrates how the interaction between content and expression affects the efficiency of emotion interpretation in remote settings. The neutral expression is the reason for confusing emotion understanding in most cases. While the nonverbal clues are missing in remote communications, the neutral expression doesn't offer sufficient affective information either, which brings more difficulties to perceive others' emotional states. This is a problem generally existing in people's daily communication. A study on augmenting the neutral expression might increase the understanding between people and contribute to social connections.

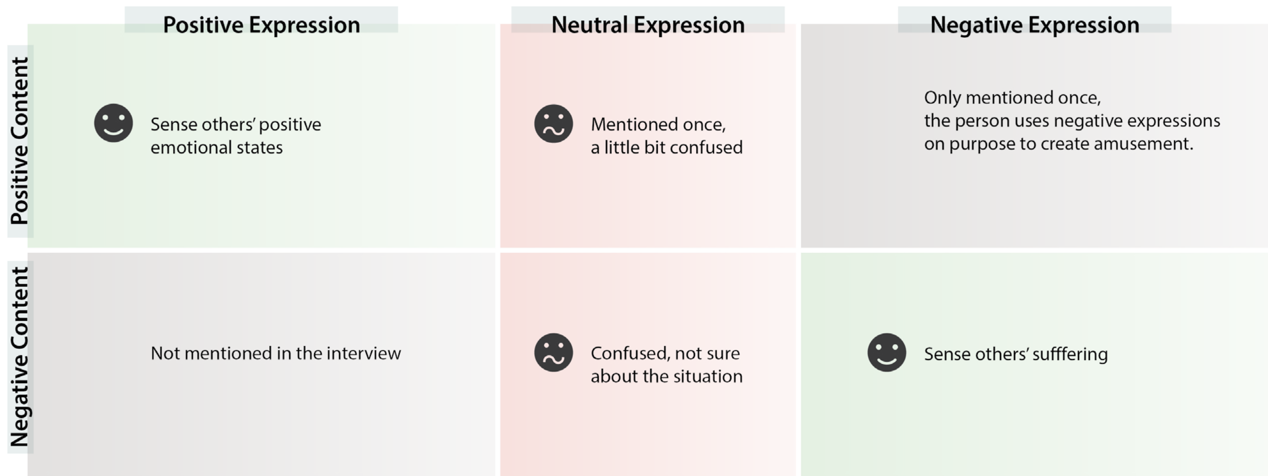


Figure 3. Emotion perception affected by contents and expressions

1.3 Emotion models

Intending to boost emotion communication, it's important to know what emotion is. In neuroscience, emotion often refers to a mental state that arises spontaneously and is often accompanied by physical and physiological changes that are relevant to the human organs and tissues such as brain, heart, skin, blood flow, muscle, facial expressions, and voice, etc. Psychologists mainly classify emotions in two approaches. The first approach divides emotions into discrete categories. The other clusters emotions on a dimensional basis. While the discrete model can only determine the category of emotion, the dimensional model describes both the category and the intensity.

Discrete emotion model

The most widely used discrete emotion model is the six basic emotions [4]. The theory summarised six basic emotions: happy, sad, anger, fear, surprise, and disgust (Figure 4), and viewed the other emotions as the production or the combinations of these basic ones. These six basic emotions are summarized according to four hypotheses by Ekman [5]: 1) People are born with emotions which are not learned. 2) People exhibit the same emotions in the same situation. 3)People similarly express these emotions. 4) People show similar physiological patterns when expressing the same emotions.

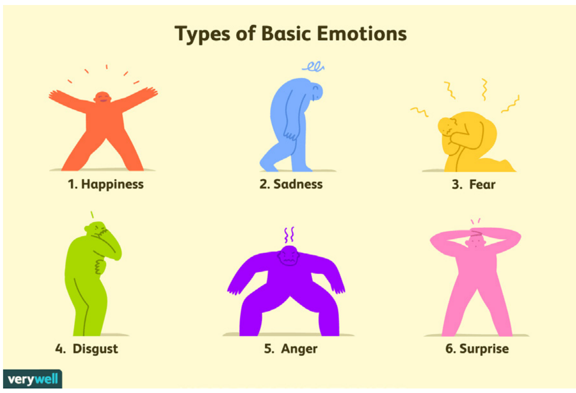


Figure 4. Six basic emotions (from Verywell / JR Bee)

Dimensional emotion model

One of the most used dimensional models is the Circumplex model by Russell [6]. In his theory, valence ranges from negative to positive and arousal ranges from passive to active. Percieving an emotion, people get both valence information (feeling positively or negatively) and arousal information (how exciting the person's emotional state is). The emotions are placed in a continuous circle, centered on a state of moderate arousal and neutral valence (Figure 5), with emotions close to each other being related.

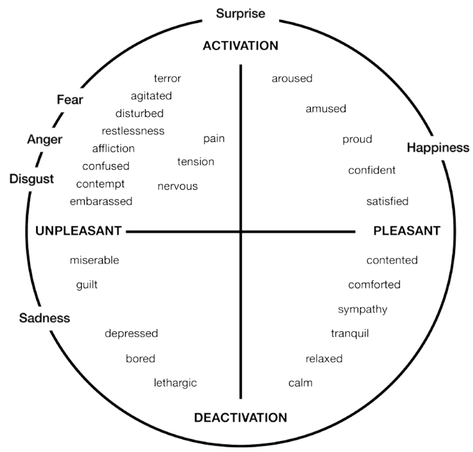
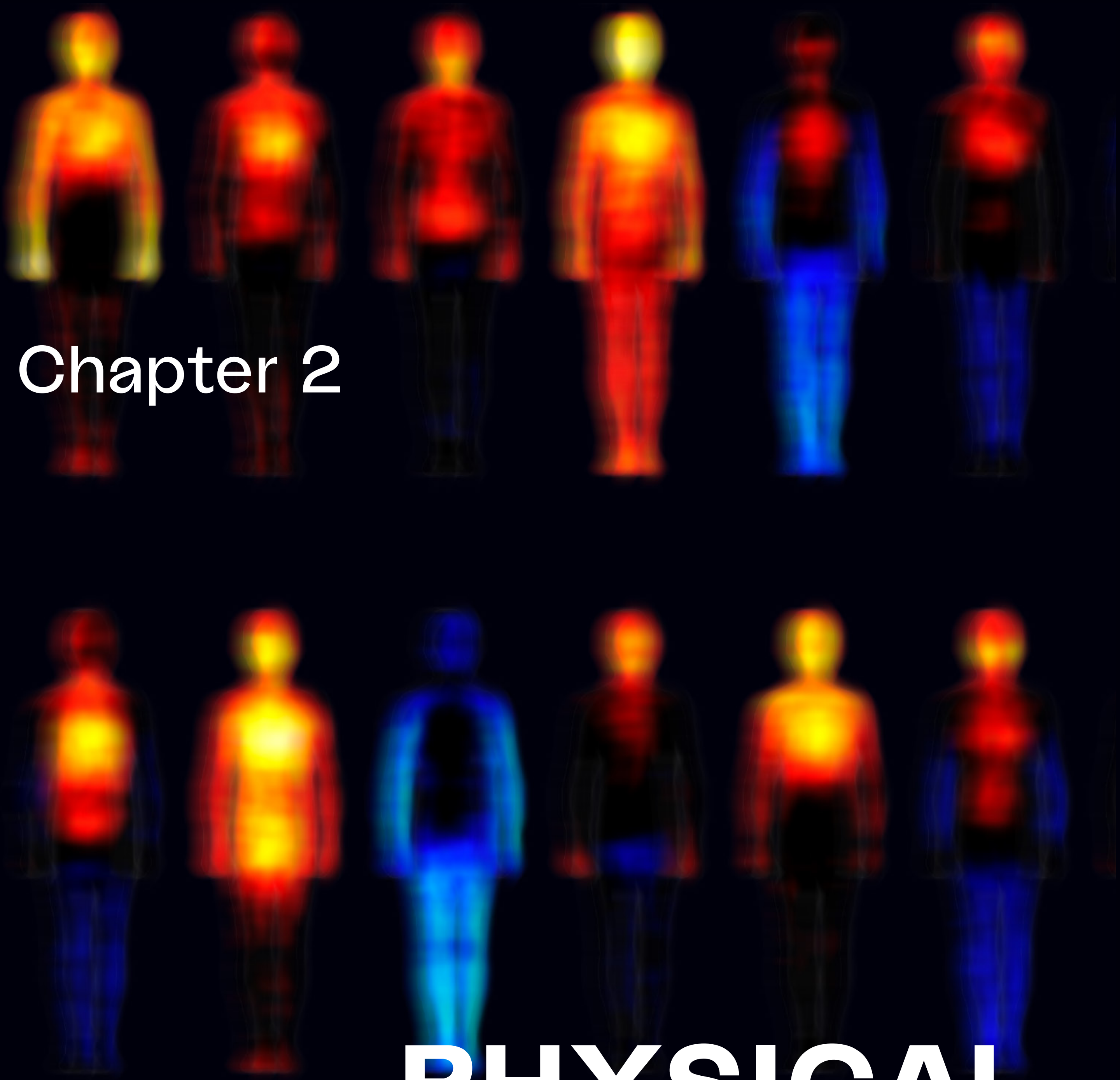


Figure 5. Circumplex model

The four general categories (quadrants) of emotion are, therefore: 1) high valence, high arousal (top-right) representing excited pleasant emotions such as happiness and excitement; 2) high valence, low arousal (bottom-right) representing calm pleasant emotions such as contentment and satisfaction; 3) low valence, low arousal (bottom-left) representing unpleasant calm emotions such as sadness and boredom; and 4) low valence, high arousal (top-left) representing unpleasant excited emotions such as anger and frustration. Russell showed that this structure held for how people structure emotion on a general cognitive level, as well as the self-reported internal experience of emotion across participants.

Emotion models in design intervention

As a project focusing on design interventions, the interest is how an emotion model fits the real-world problem. Comparing the two approaches, the discrete model sets clear boundaries between different emotions while the dimensional model emphasizes the intensity of the emotional state without specifying what the emotion is. Which model to use depends on the characteristics of a project. For example, if a designer or researcher wants to collect the emotional feedback of a product on a quantitative level, the dimensional model is useful since it allows people to give ratings on both valence and arousal. If the detailed emotion is of interest, the discrete model is the choice as it enables people to differentiate one emotion from another during self-reporting. In this project, the dimensional model is mainly applied to collect quantitative feedback in terms of valence and arousal.



/ Chapter 2

PHYSICAL EMOTION PERCEPTION

Introduction

As Lauri Nummenmaa et al. put in their paper [1], human often experience emotions directly in the body. Therefore, when pure verbal communication can't always convey affective information sufficiently, creating new channels can be an option. Apart from the verbal modality, the physical stimulus is a potential direction to explore. Combined with the theory of emotion perception, this chapter describes how physical stimulus would augment a neutral voice message. Besides, the choice of studying thermal stimulus as the extra communicating modality is made based on the review of the related research.

2.1 Embodying emotion

Models of embodied emotion posit that we understand others' emotions by simulating them in our bodies [7]. Neuroimaging studies have revealed that recognizing a facial expression of emotion in another person and experiencing that emotion oneself involve overlapping neural circuits (Figure 6). Therefore, the emotion elicited by similar bodily responses might immerse a person with others' feelings. This might open a door to enhance emotion interpretation with physical stimulation. The core question is how human perceive others' emotions with physical stimulation. To answer the question, the emotion perception process is introduced in the following section.

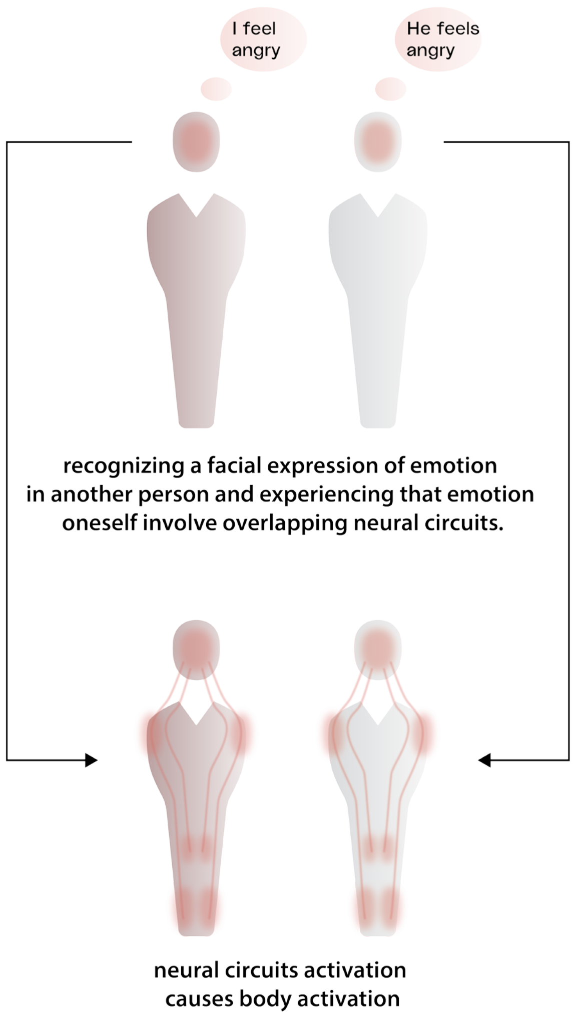


Figure 6. Experiencing other's emotion by overlapping the same neural circuit

Emotion perception

Emotion perception refers to the ability to make accurate decisions about another's subjective experience by interpreting their physical changes through sensory systems responsible for converting these observed changes into mental representations. It can be understood as the following processes after the presence of an emotive stimulus [8]: 1) the appraisal and identification of the emotional significance of the stimulus. 2) the production of a specific affective state in response to the stimulus, including autonomic, neuroendocrine, and somatomotor (facial, gestural, vocal, behavioral) responses, as well as conscious emotional feeling. 3) the regulation of the affective state and emotional behavior, which may involve an inhibition or modulation of processes 1 and 2, so that the affective state and behavior produced are contextually appropriate. Figure 7 illustrates the emotion perception process.

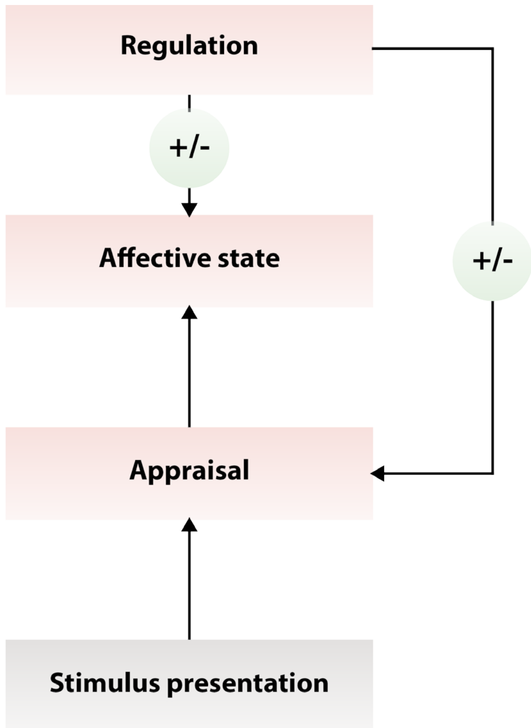


Figure 7. Emotion perception process

Physical emotion experience

Human experience emotion physically. Jamesian's theory was modified to argue that emotional experience is a product of the cognitive appraisal of bodily arousal [9]. The model remains controversial. The critics argue that bodily responses occur relatively late in the information-processing chain and are therefore best viewed as a consequence rather than the cause of cognitive-affective activity [10]. However, research [11] has revealed that both the generation and the perception of bodily responses are essential sources of variability in emotion experience and intuition. The ability to detect the subtle changes in bodily systems, including muscles, skin, joints, and viscera, is referred to as interoception. According to both psychological theory [12] and actual studies [13] [14], the insula representing interoception highly affects cognitive-affective processing and is related to emotion experience. Therefore, motivating the affection-related bodily changes would serve as an extra source in emotion experience, which might contribute to emotion interpretation. Considering the emotion perception process, the physical stimulus might enrich the stimulus presentation with an extra dimension.

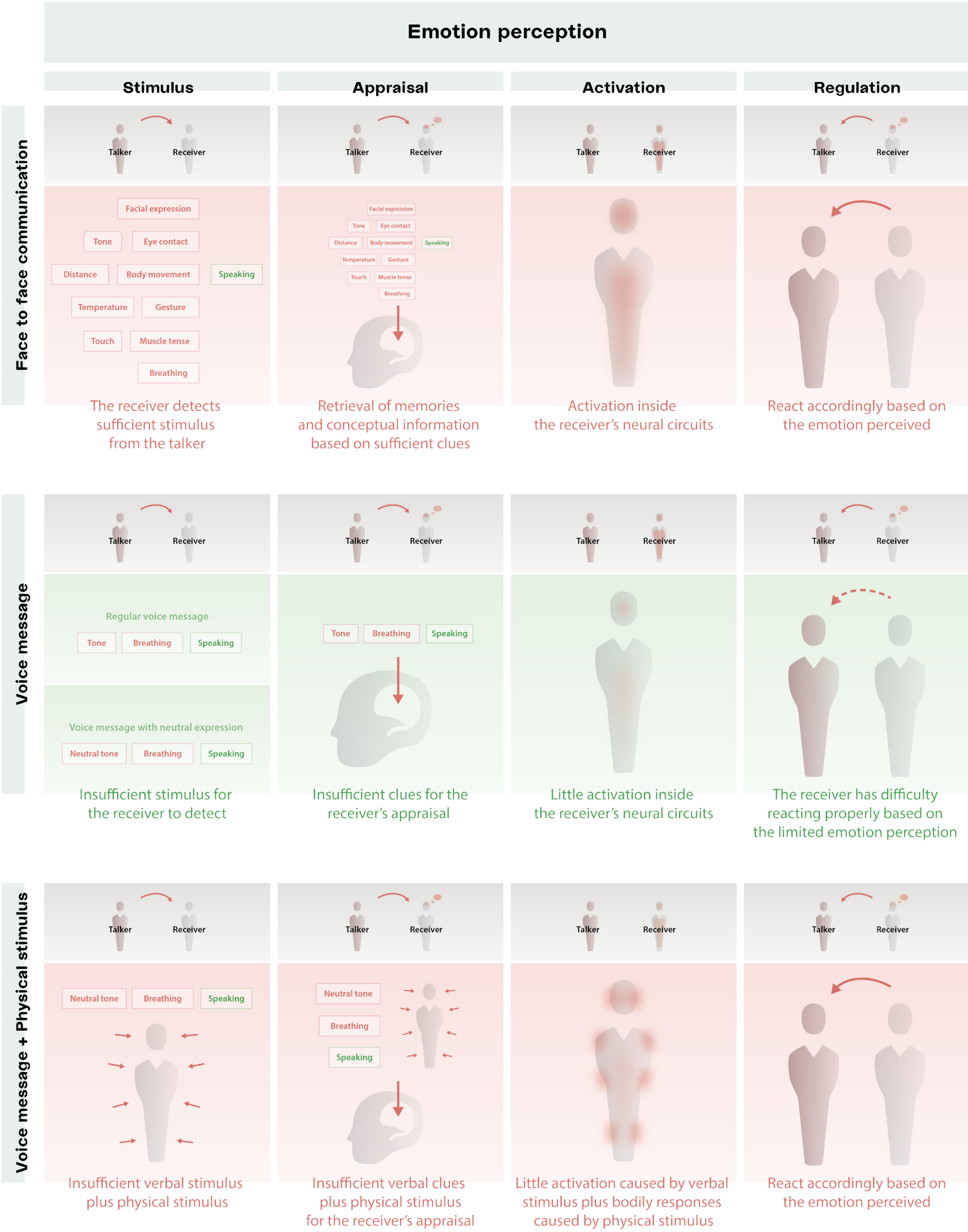


Figure 8. Affecting emotion perception with physical stimulus in the context of voice message

2.2 Emotion perception with physical stimulus

Aiming to explore emotion perception with the physical stimulus, I narrow down the scope to the voice message as the remote communication scenario, which is less explored compared to text-based on previous research. Figure 9 illustrates the assumption developed based on emotion perception theory in the context of the voice message.

As shown in Figure 8, people usually have rich clues (e.g., speaking, tone, eye contact, facial expression) to interpret others' emotional states during a sufficient emotion perception process. Appraising these stimuli, the neural circuits related to certain emotions are activated, which leads to the activations inside the human body. Then people actually "feel the emotion". When it comes to the voice message, only the linguistic factors are available. If they are expressed neutrally, the stimuli are even more limited. The insufficient stimuli are not enough for emotion appraisal and might lead to a lower activation in the neural circuit, which means lower body activation. Thus, people can't get a clear sense of emotion.

Assumption

In my assumption, the external stimulus will be added as an extra channel. When appraising the emotional states, people get not only linguistic elements but also the physical stimulus related to emotional experience. The expectation is that the physical stimulus will contribute to emotion perception and augment the emotional experience from a neutral voice message.

2.3 Physical stimulus in social interaction

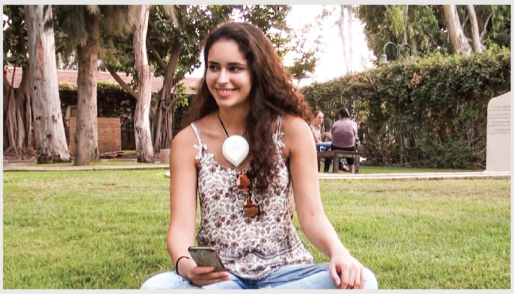
Thinking about conveying affection through physical stimulation, what modality to use is the first question. There are already some explorations on communicating with physical stimulus. Most of these explorations are from the research area. The modality mostly studied are haptics and thermal. The following sections present a review of the related work.

Haptics

Haptics is a widely explored modality in the topic of tangible communication. Some projects apply haptics to simulate activations related to arousal. Others are using the characteristics of touch to convey information about the same feeling. Figure 9 presents the projects mentioned in this section.

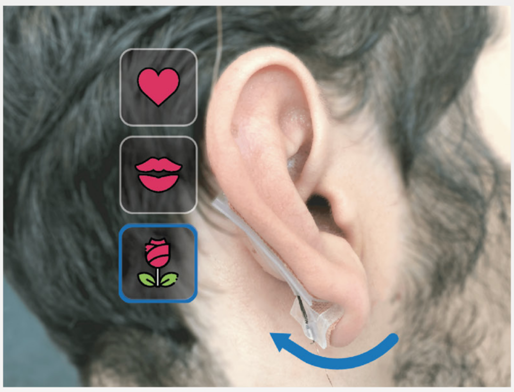
Immersing other's feelings with a false heartbeat is an example of activation simulation. HaptiHeart, as a pendant attached to clothes, is designed to communicate heartbeat [15]. It simulates the heartbeat on the chest to immerse a person with his or her partner's feelings. Breeze is a pendant that presents breathing as biofeedback to others and has it understood emotionally [16]. It involves not only vibration but also sounds to simulate breath and uses light to offer a reminder. The HugShirt is a shirt to send hugs over distance. It delivers the hug from others through offering pressure feedback [17]. Springlets is a novel class of SMA-based tactile interfaces for the expressive, non-vibrotactile output with a soft and discrete form. It can be worn like stickers [18]. It communicates feelings or intentions in intimate relationships according to the quality of its interaction. The smooth and silent operation enables it to communicate non-critical, enjoyable events, such as receiving an intimate tactile message from a remote partner to communicate "I miss you".

HaptiHeart: a gadget communicating heart beat



Breeze: a pendant presenting breathing as affective information

HugShirt: a shirt delivering hug over distance



Springlets: a SMA-based tactile interfaces for expressive, non-vibrotactile output

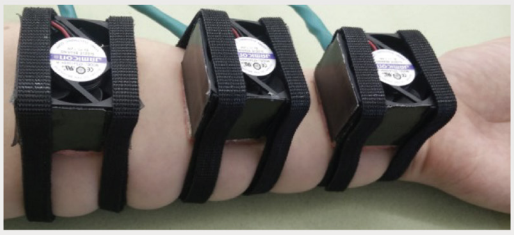
Figure 9. Research about communicating emotion with haptics

Thermal stimulus

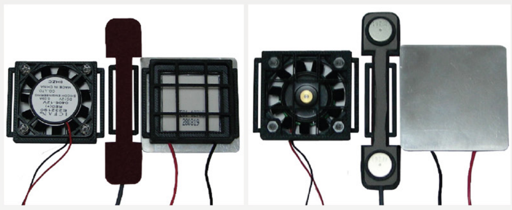
Thermal stimulus is another important modality in affective communication. Thermal sensation is a key component of the conceptualization and experience of emotion: physical warmth increases interpersonal warmth [19][20] and the experience of physical temperatures helps to ground and process emotional experience [21].

Because of its link with emotion, thermal feedback is becoming a hot topic in research. The studies introduced in this section are illustrated in Figure 10. SWARM is a scarf that serves as emotion perception facilitation on two aspects [22]. First, it helps people with autism to identify their own or others' emotions. Besides, it helps people with disabilities (e.g., blind people have no clues about other people's facial expressions) to understand others' emotions. The system not only alerts the users of a change in their emotions but also attempts to mitigate negative emotions and enhance positive ones in real-time using actuations. The system involves three kinds of stimuli: heat, vibration, and music. The test result indicates that people regard heat as a better channel to communicate emotion while the vibration feels more like an alert. TAD is an on-arm device which offers thermal cues signaled with an array of three TECs [23]. The thermal array influences the emotional communication in the text message, especially when the message is neutral. The result shows that TAD consistently affects arousal, especially arousal of more emotionally neutral text messages. Some projects are focusing on the specific emotional experience related to the heat change inside the body. HaptiTemper is a device aiming to boost fear physically [15]. It simulates the feeling that “chills down/up human body’s spine” through both cold airflow from DC fan and the cold side of Peltier element. It is also intended for simulation of warmth on the human skin to evoke either pleasant feeling or aggression based on the quality of thermal sensation.

SWARM: a scarf serving as emotion perception facilitation



TAD: an on-arm device offering thermal cues signalled with an array of three TECs.



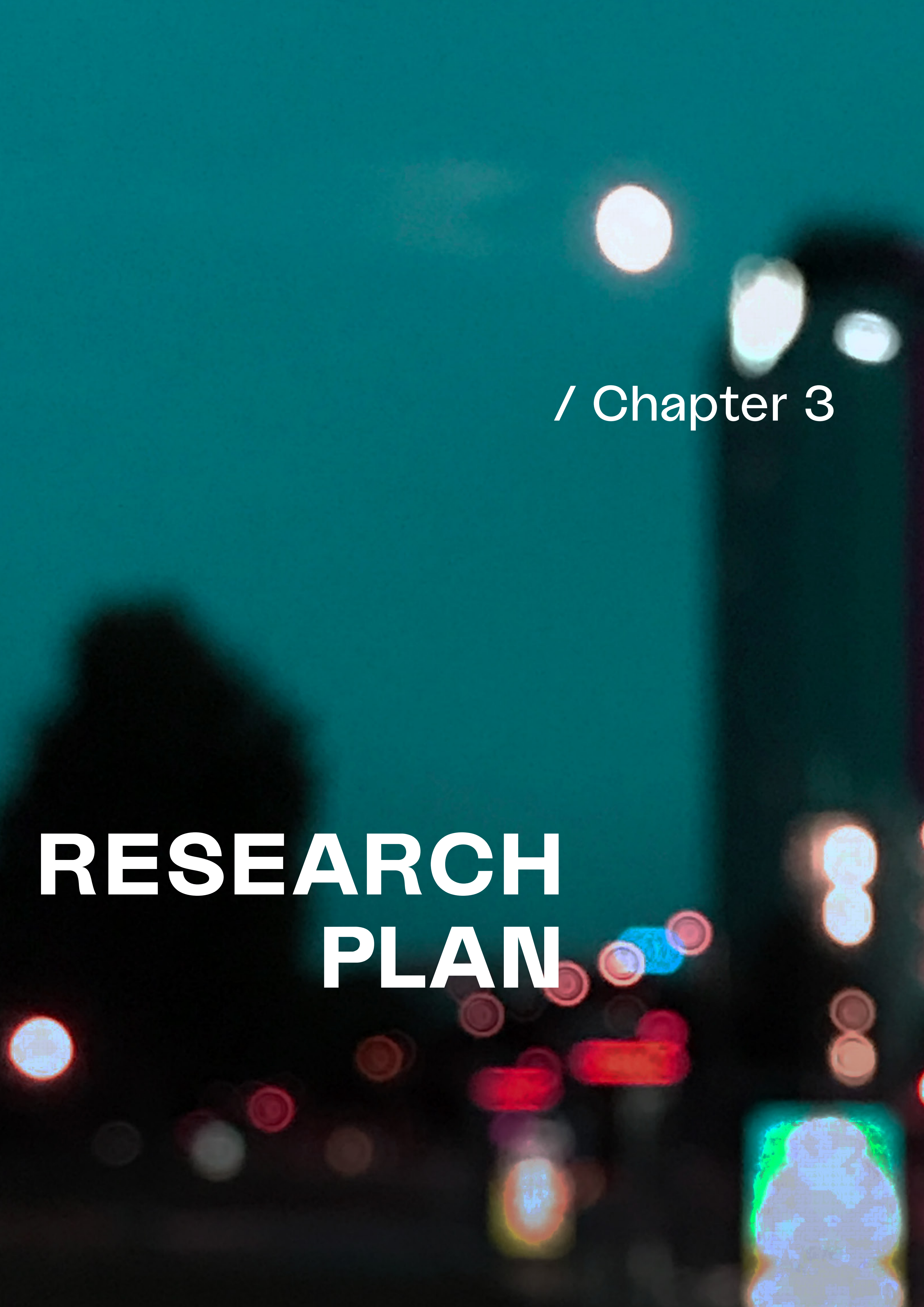
HaptiTemper: a device boosting fear with thermal stimulus.

Figure 10. Research communicating emotion with thermal stimulus

Summary

For both haptics and thermal stimulus, researchers are trying to apply their links with emotional experience when mapping the stimulus to affective information. Haptics build the connection with affection through two ways: 1) certain activations like heart beat or breathing. 2) touch with certain meanings like hug. For thermal stimulus, the connection seems more general since the thermal sensation already carries affective information. In this project, the thermal stimulus is chosen as the modality to explore for the following reasons. First, thermal sensation is highly related to the activations inside the human body. When an emotion is felt, a certain part of the body is activated. The blood flowing in that part increases and might cause a higher local body heat. These features make thermal stimulus suitable to communicate emotions on a general level without restricted to a certain context like a hug from lovers. Besides, privacy is a general concern when it comes to sharing emotion information. Thermal stimulus, compared to other modalities, has a better effect on keeping the feedback unnoticed by others. Therefore, this project focuses on thermal, which is explored to a limited extent as a potentially interesting means of communication and interaction.

Laying the focus on thermal displays, many of the previous research mainly focuses on the effect of using thermal as signal delivery. When looking into the relationship between thermal stimulus and emotion, many contexts are still waiting to be explored. Verbal conversation is one of them. Considering the hardware, two elements are usually applied in this field - conductive fiber [24] and Peltier element [15] [23]. For the conductive fiber, it's easy to be integrated with fabrics but can only offer warm stimulus. Considering emotion can be either positive or negative, the single changing direction of the temperature will limit the mapping between thermal stimulus to emotion. Therefore, the Peltier element, a commonly used actuator which can offer a warm or cold stimulus, is applied in this project.



/ Chapter 3

RESEARCH PLAN

Introduction

Based on the research on communication issues, embodying emotion theory and affective computing practices from HCI field, the research question is formulated in this chapter. To conduct the research, the study plan is proposed.

3.1 Research question

While chapter one raises the problem of confusing emotion interpretation caused by the neutral expression, chapter two indicates that adding thermal stimulus as extra channels for affective communication could be a potential direction. Therefore, the research question can be framed as follows:

How can wearable thermal display contribute to emotion interpretation from neutrally spoken voice messages?

3.2 Study plan

The starting point of this research is a real-world problem - people have difficulties interpreting others' emotional states from neutral expressions. Aiming to explore how thermal stimulus can be applied to solve the problem, the research is simplified and abstracted into controlled experiments. With the main focus on affective thermal stimulus, the wearability is also an aspect considered when developing the wearable thermal display. The study follows the path of research through design. Prototypes are built to conduct experiments and collect feedback for the research question.

The study will be conducted in three steps. First, a pre-study is conducted to verify some elements (e.g., body location, the contact medium) used in the formal experiments. Afterward, the first experiment is performed to explore the thermal perception in terms of intensity and comfort from different contacting mediums (fabric or naked skin). The findings are used to verify the intensities of the thermal stimulus and the contact medium for the second study. The second study aims to explore how thermal stimulus can augment emotion interpretation from neutral voice messages, which is the core question of this research. Throughout the study, prototypes are built and iterated for conducting experiments. Figure 11 illustrates the process of the study.

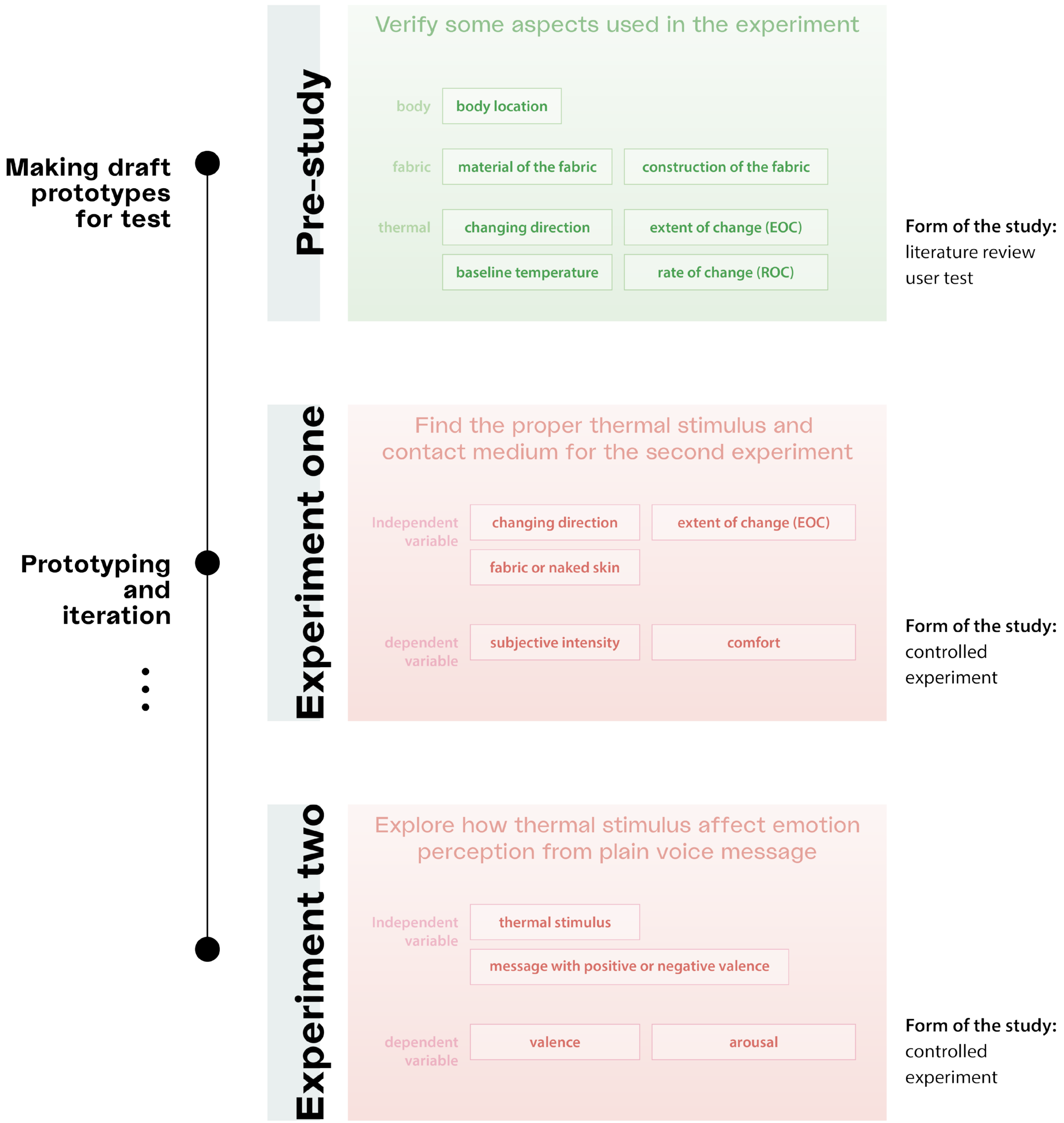
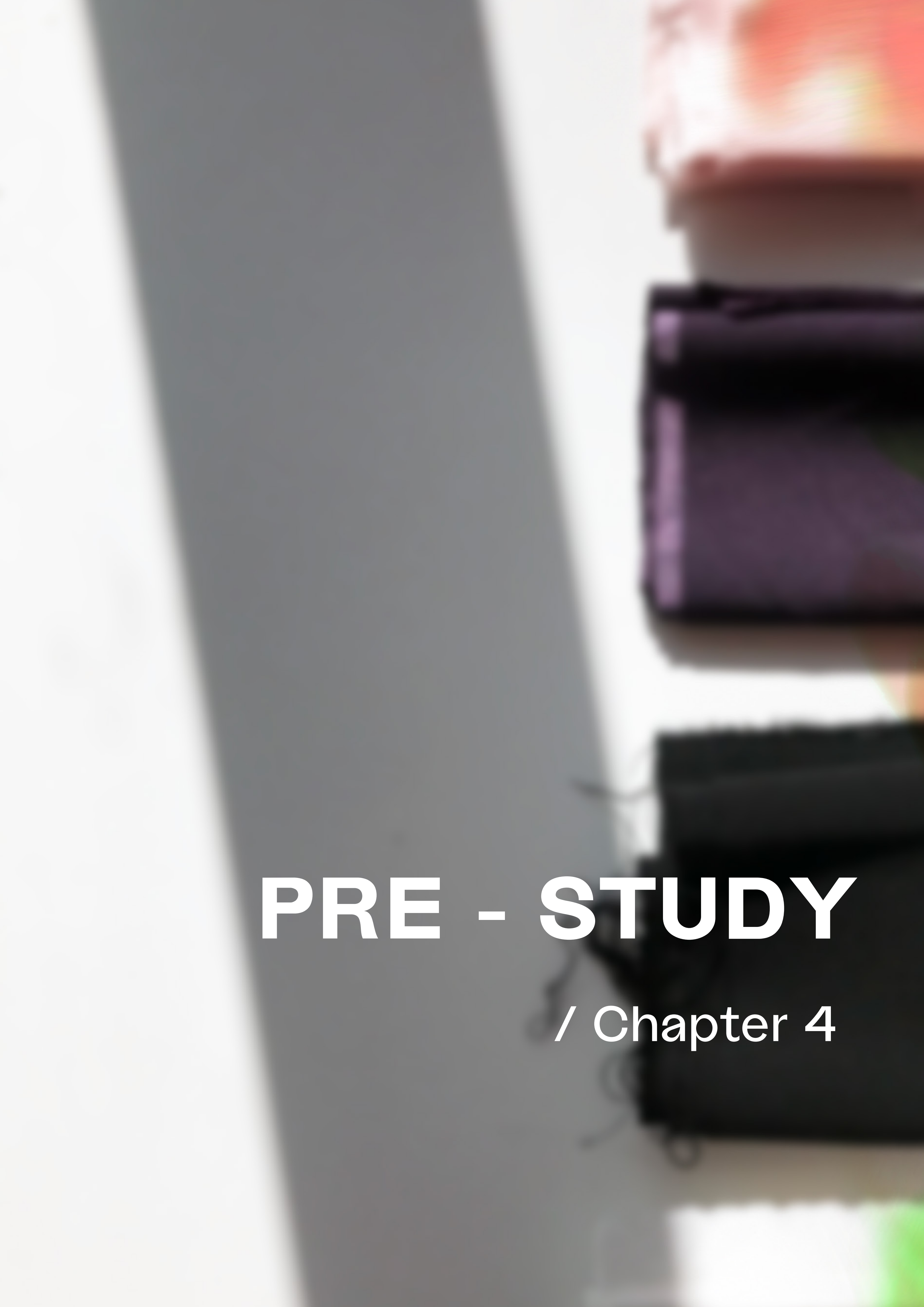


Figure 11. The study plan



PRE - STUDY

/ Chapter 4

Introduction

This chapter introduces the process and results of the pre-study. The pre-study helps to determine some factors related to the experiment. The elements explored during the study are 1) body location to perceive the thermal stimulus. 2) the construction and material of the fabric. 3) parameters of the thermal stimulus including the baseline temperature, the extent of change (EOC) and the rate of change (ROC). The study is conducted by the means of both literature review and user tests.

4.1 Body location

To design a wearable thermal display, the body location for the stimulus is first considered. The choice is made based on two aspects: 1) affective communication. 2) wearability.

Body map of emotion

The body map of emotion (Figure 12) shows that there is a relationship between different emotions and activations of the body location [1]. From the map, the activation inside the body mainly changes in trunk and limbs when people are feeling emotions. The activation can increase or decrease depending on the emotion felt. Therefore, to simulate the emotional experience, trunk and limbs are potential options.

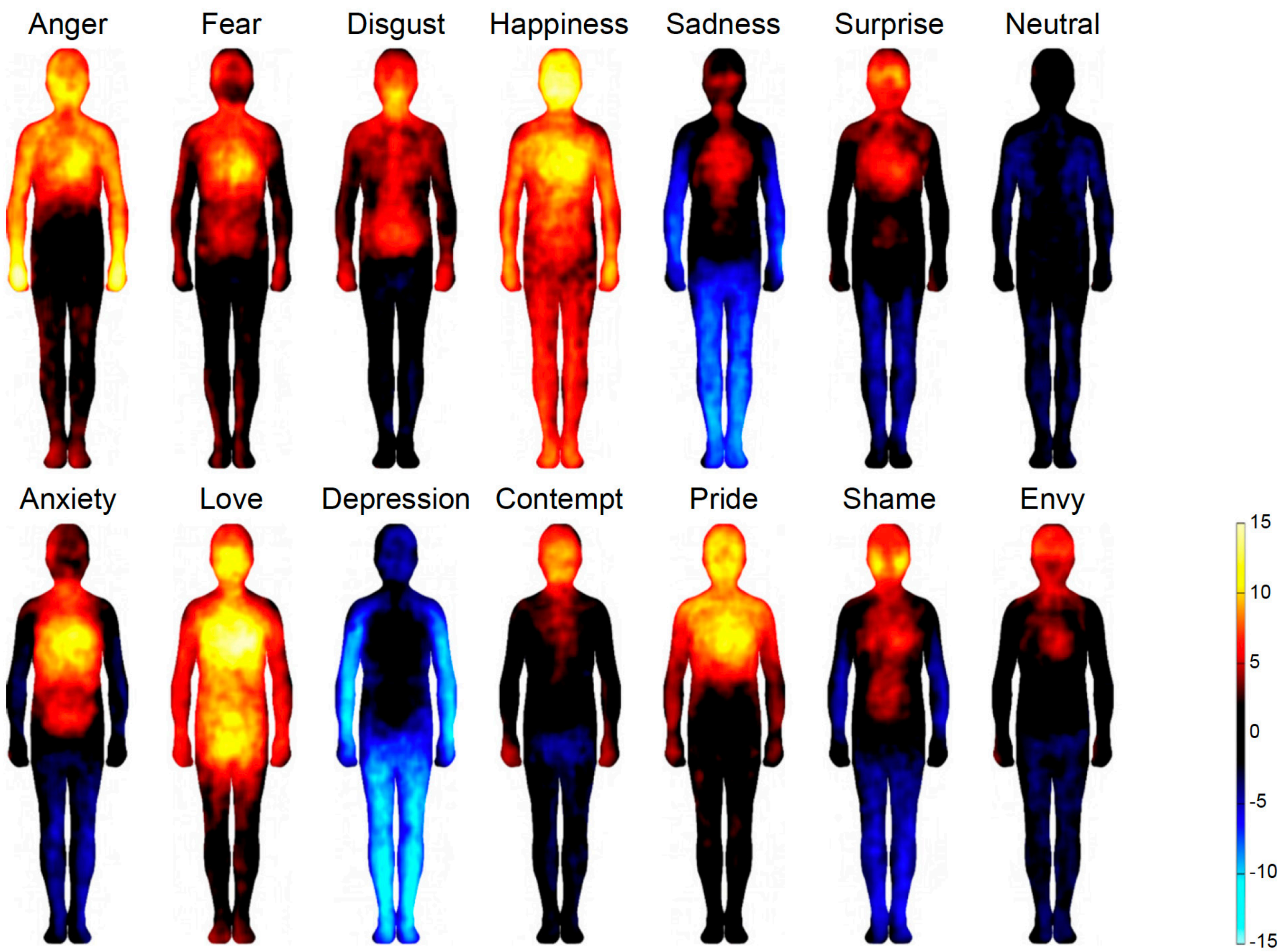


Figure 12. The body maps showing regions whose activation increased (warm colors) or decreased (cool colors) when feeling each emotion

Wearability

To address the wearability, Zeagler's wearability guideline [25] was taken into consideration. Most choices in on-body location come down to a balance between the desired use of the wearable device and the affordances different parts of the body offer. Zeagler creates a series of body map from synthesizing the affordance found in literature according to different considerations. His considerations include: Proxemics, Weight Distribution, Body Mechanics and Movement, Movement Sensing Consideration, Thermal Tolerances, Biometric Sensing, Tangible / Tactile / Haptic Feedback (passive touch), Touch (Active Touch), Reach-ability, Visible Feedback, Networking on the body, Manufacturing for Garments and Social Acceptability.

Among the thirteen maps, I chose three which are highly related to my topic: 1) Body Mechanics and Movement. 2) Manufacturing for Garments. 3) Social Acceptability. The three maps are shown in Figure 13.

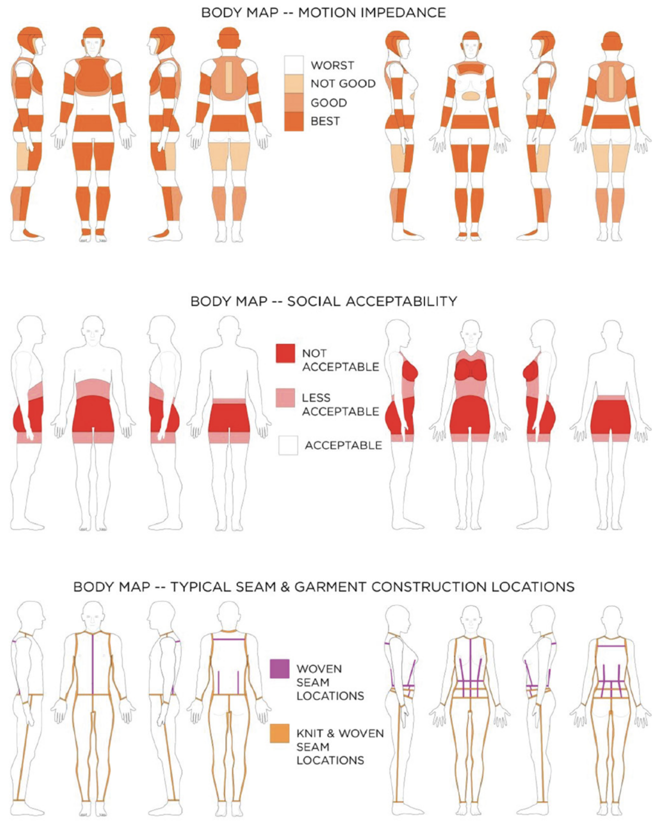


Figure 13. Three body maps on wearability related to the project

I overlayed the three maps to find the common areas, which led to a body map fitting the requirement in terms of the three factors. the map created is shown in Figure 14. From the new map, the areas are head, forearm, upper arm, upper chest, the front of thigh, the front of shin and instep.

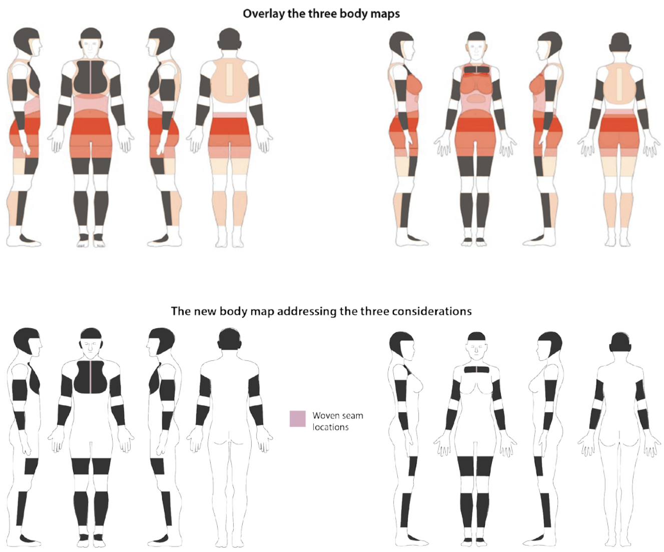


Figure 14. The new body map addressing mechanics and movement, manufacturing for garments and social acceptability

Summary

According to emotion body map, upper chest and forearm are the locations always having activation changes when experiencing emotions. These two locations are also within the options offered by wearability body map. Therefore, the forearm and upper chest are the potential locations to place actuators and add thermal stimulus. Considering the time limitation, the upper chest is chosen as the body location in this research.

4.2 Fabric as contact medium

To build a wearable display, it's important to consider the feasibility of using fabric as a suitable contact medium. Generally, adding an extra fabric layer between actuators and skin always weakens the thermal sensation. Therefore, the aim is to study the potential of using a piece of fabric to convey thermal stimulus with the comparison of naked skin. Since the stimulus is offered by wearables for communication, the fabric used should have a high thermal conductivity without delaying the real-time conversation. Besides, the feeling of touching the fabric apart from thermal sensation should be relatively neutral without much effect on emotional feelings. Last but not least, the construction of the fabric should hold a stable structure for the electronics.

What worth mentioning is that the contact medium refers to the inner layer of the fabric, which sits between the actuator and skin. The inner fabric layer is embedded inside a regular garment, which can be seen as the outer layer. Figure 15 illustrates the structure. I chose elastic fabric as the outer layer. The fabric used for the outer layer is knitted and stretchy compression fabric. It enables the actuators sitting close to the human body. Besides, the fabric is suitable to make garments for multiple sizes, which makes it the appropriate material for experimenting.

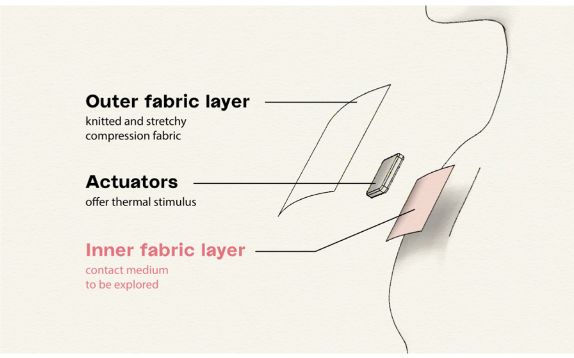


Figure 15. The structure of the two layers with the actuator in the middle

Woven or knitted

Thermal conductivity of fabric is a complex parameter. All fabrics can be described by referring to their fiber composition and weave, or type of knitting used to create them. Weaven and knitting are the most basic methods for fabrication. Figure 16 illustrates the difference between them.

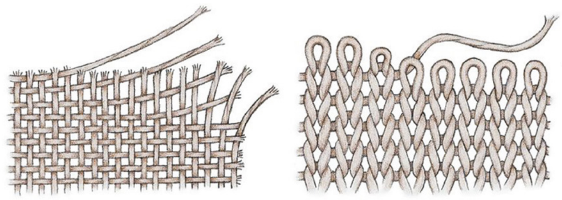


Figure 16. Weave and knit

While the conductivity of polymers and yarns are all similar, the way of constructing the fiber into a piece of fabric dominates the thermal conductivity. Different construction and finishes will lead to different thickness and roughness. If the fabric is thick and rough enclosing lots of air, the conductivity is much lower. Majumdar [26] has demonstrated that thermal conductivity decreases with increase in fabric thickness. Research has shown that knitted fabrics have lower values of thermal conductivity in comparison with woven fabrics because they are generally thicker than that of woven fabrics [27]. Therefore, considering the thermal conductivity, woven fabrics are the better choice.

Another consideration is which one is better to be built with electronics. Two draft demonstrations were made to explore the problem. I sewed an extra layer on a piece of stretchy fabric with knitted fabric and woven fabric respectively. A Peltier element was embedded between the two layers (Peltier element is used to offer thermal stimulus in this project. A detailed description of Peltier element is presented in the next chapter). Figure 17 shows the condition with a piece of woven fabric as the inner layer.

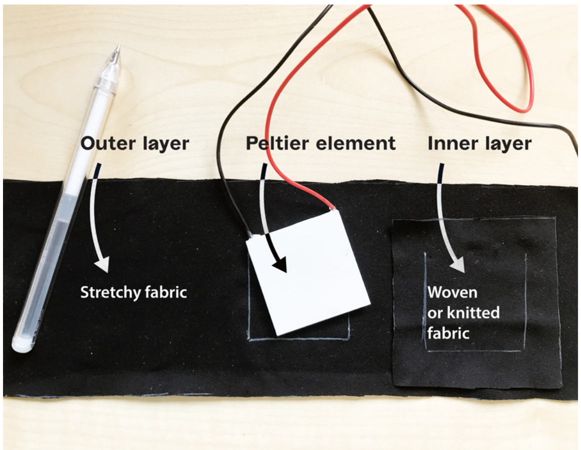


Figure 17. The material used for the draft demonstration

I mainly tested if there was a difference in the stability of the Peltier element's location when the fabric is stretched by force. Figure 18 shows the shape change in two conditions. From the test, there is no much difference between the two materials. However, the space made of woven fabric has less change, which enables less waggle of the actuators. Therefore, the woven fabric offers a more stable structure.

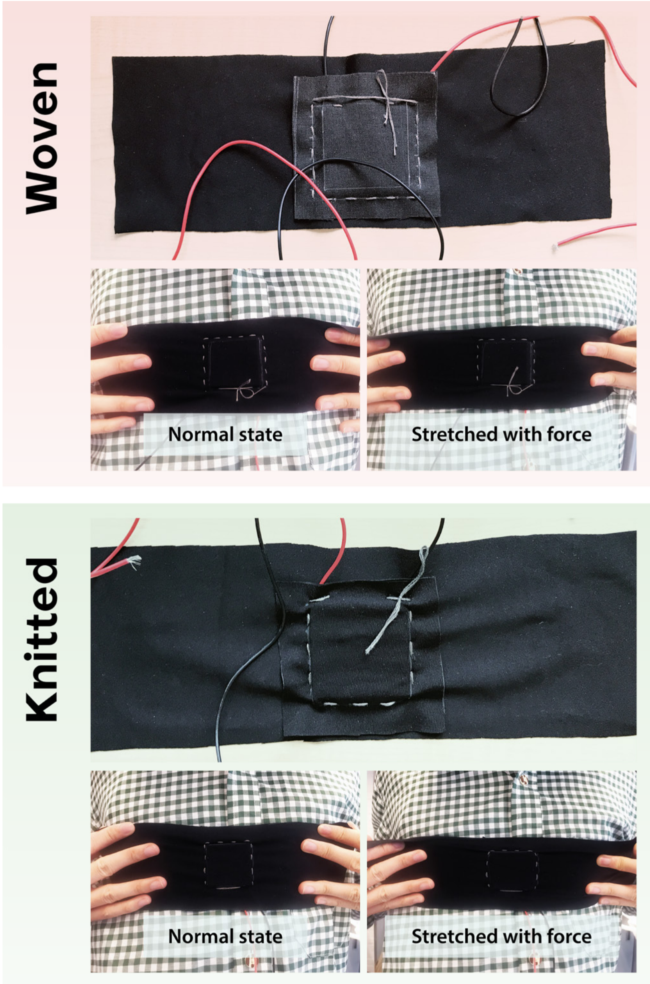


Figure 18. The shape change of woven and knitted fabrics when stretched

Material

Since the fiber composition doesn't affect thermal conductivity very much, I mainly collected people's feedback about four materials in terms of comfort when the thermal stimulus is added. The fabric is only a medium to convey signals. Therefore, the feeling of touching the fabrics should be relatively neutral and smooth instead of irritating. The four materials are cotton, wool, silk, and polyester. The components of each fabric are shown in Figure 19. I did a quick test with three participants (including

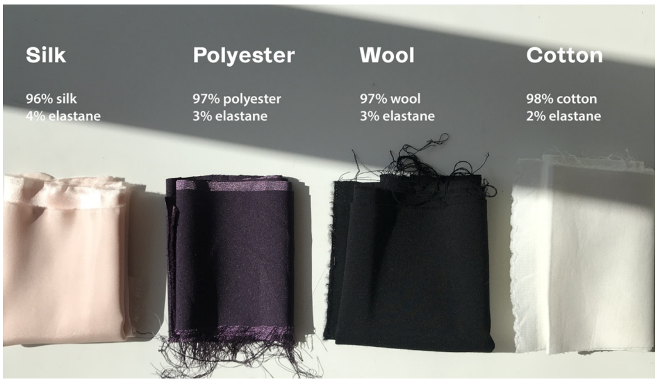


Figure 19. The compnents of four fabrics

myself) in a room with the temperature of 23°C. I made four simple armbands by sewing a bag of certain material on a piece of stretchy fabric (Figure 20). For each participant, I asked them to put on the armband and then let them experience warm and cold stimuli with 4V on the forearms (Figure 21).

Figure 20. The bag made of four materials

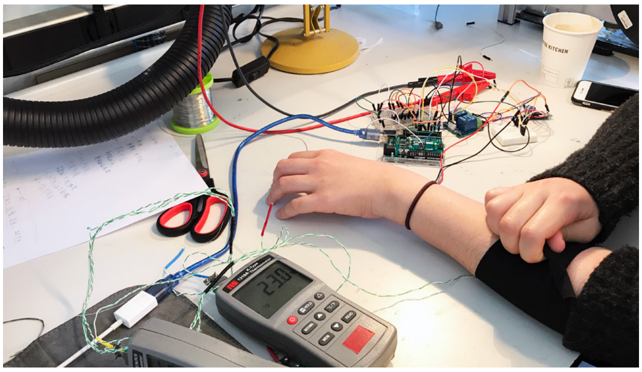


Figure 21. Exploring the comfort across four fabrics

During the process, they were encouraged to think aloud. After the four materials were tested, two open questions were asked: 1) Talk about the subjective comfort of the fabrics. 2) Talk about the thermal sensation. The quotes of their feedbacks are presented in Table 2.

participant	Wool		Silk		Polyester		Cotton	
	silk-heat	wool-cool	silk-heat	silk-cool	polyester-heat	polyester-cool	cotton-heat	cotton-cool
P1	*slightly uncomfortable* *I felt less heat but the touch is a ilttle bit tingling.*	*slightly uncomfortable* *The heat change quite fast. Too intense.*	*between comfortable and slightly uncomfortable* *It changes slowly and gentle. I feel the stimulus area is a surface.*	*between comfortable and slightly uncomfortable* *It changes faster than polyester. It feels even better when the temperature change stops and remains.*	*between comfortable and slightly uncomfortable* *It changes gently. I feel the stimulus area is a surface.*	*comfortable* *I don't feel the existance of the fabric when the change stops. It feels gentle.*	*uncomfortable* *It doesn't breathe with the heat. The heat area is limited to a specific area.*	*between comfortable and slightly uncomfortable* *It chnages fast. The stimulus is not spreaded all over the fabric.*
P2	*slightly uncomfortable* *It feels tingling.*	*slightly uncomfortable* *It feels intense, It changes too fast, not very comfortable.*	*between comfortable and slightly uncomfortable* *It changes faster and more comfortable than the wool. I feel the stimulus area is bigger.*	*between comfortable and slightly uncomfortable* *It feels even better than heating up. The stimulus is gentle and comfortable.*	*between comfortable and slightly uncomfortable, a little bit better than silk* *It feels slow and comfortable. The stimulus area feels more like a surface instead of a point.*	*between comfortable and slightly uncomfortable, similar to silk* *The fabric doesn't reject me. I don't feel the existance of the fabric. It's a kind of gentle cold.*	*uncomfortable* *It's fine. It feels uncomfrtable, It's unsmooth. The heat doesn't feels good on thisÅ material.*	*uncomfortable* *Just uncomfortable.*
P3	*slightly uncomfortable* *It feels Itchy. The heating area is like a point.*	*slightly uncomfortable* *It feels Itchy.*	*between comfortable and slightly uncomfortable* *It feels comfortable.*	*between comfortable and slightly uncomfortable* *It changes too fast. The stimulus spreads from a point to the area quickly.*	*comfortable* *The heating is even across the area. The most comfortable one, like a infrared therapy.*	*between comfortable and slightly uncomfortable* *At first, it's a point. Then it spreads into an area.*	*between comfortable and slightly uncomfortable* *It is fine.*	*comfortable* *It cools down gently.*

Table 2. Results of thermal comfort across four fabrics

The silk was selected based on the feedback. Among the four materials, wool showed some clear drawbacks. It made people itchy and the thermal stimulus felt intense through it. Polyester was the most comfortable one. Participant three even mentioned that it was like an infrared therapy. However, comfort might cause pleasure that brings intervention in affective communication. Considering that the project aims to communicate emotion, polyester was not selected. Between cotton and silk, the latter received less negative feedback. Two people (P1, P2) felt that the heat spread unsmoothly on the cotton. Therefore, The silk with little elastane was chosen for the main study, which is lightweight silk with the inclusion of Lycra in the weft.

Summary

Woven silk with little elastane was chosen as the contact medium for the prototype. The woven fabric enables a higher thermal conductivity and a stable structure for the embedded actuators while the silk feels relatively neutral without irritating feelings.

4.3 About thermal stimulus

Since the project aims at applying thermal stimulus for communication, research on using thermal stimulus as signals were reviewed. The review from the previous work helps to determine the parameters of the thermal stimulus for this study.

Changing direction, baseline temperature & extent of change

The changing direction and extent of change (EOC) are two of the most basic elements in terms of thermal sensation. In the experiment, I choose 32°C as the baseline temperature. The low intensity is 3°C and the high intensity is 6°C. The rationale of this choice is based on the consideration of offering distinguishable and safe stimulus. The skin sits at a neutral temperature of 30-36°C, depending on the individual. Detection of changes within this range is dependent more on the rate of change (ROC) of the stimulus than the actual extent of change itself. Outside of this range, human become more sensitive to changes that move further away from neutrality towards the pain threshold [28]. Considering my project, the baseline temperature is the temperature of the touching area between the skin and the Peltier element. Previous research usually used 32°C as the baseline temperature [23][29]. I validated the temperature with three people including myself in a room with the temperature of 23°C. I measured the temperature of the touching area of skin and the Peltier element with a thermometer first. After the Peltier element was attached to the arm for two minutes, which is long enough for the temperature adaptation between the skin and the element, I measured the temperature of the touching area again. Table 3 shows the result of the measurement.

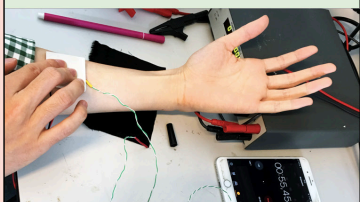
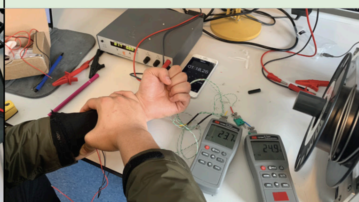
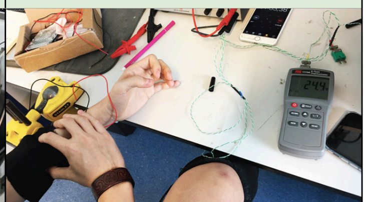
participant	P1	P2	P3
			
Skin temperature (°C)	34.0	34.0	34.6
Peltier element (°C)	25.6	25.7	26.2
Touching area (°C)	32.4	31.0	32.0

Table 3. Validation of the baseline temperature of the touching area

From the result, the temperature was around 32°C, which was chosen as the baseline temperature. The Halvey et al. [30] presented thermal stimuli in conjunction with images or music, and chose ±6°C as the warm or cool changes. This project follows his choice by applying 3°C and 6°C as the low and high intensity respectively with the neutral temperature at 32°C.

Rate of change

Within the context of conversation, the voice message is usually short in time. However, the Peltier element used in the experiment needs time to reach a higher or lower temperature. The conflict is very important to consider from an application perspective (e.g., when the stimulus is added to the required level, the content of the conversation might already have changed). Therefore, the rate of change (ROC) should be high enough to keep at the same pace as speech. ROC is directly related to the voltage applied to the element. Therefore, the method used to control voltage determines ROC. For experiment one, to get a constant temperature change, Peltier element was controlled by PID control, which determines ROC. For experiment two, ROC was increased without PID control because the stable temperature was not needed. More explanations about the ROC applied will be presented in the next chapter.

PROTOTYPING

/ Chapter 5

Introduction

This chapter presents the prototyping process. The operating principle and characteristics of the Peltier element are first introduced. Afterward, the method and material used for building the prototype are described. The problems encountered during the process and the solutions applied are documented.

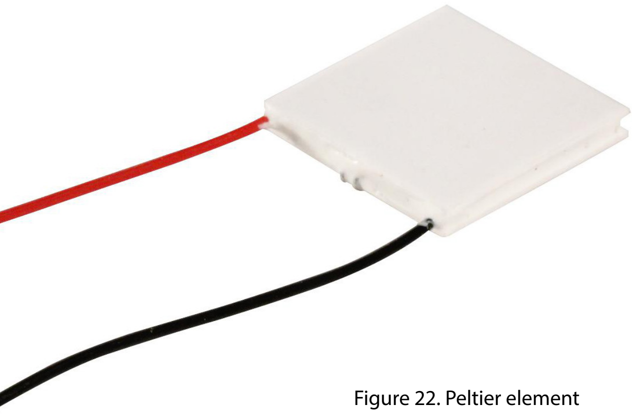


Figure 22. Peltier element

5.1 Peltier element

Peltier element (Figure 22) is a solid-state semiconductor active heat pump. It was selected as the actuator because it can offer both warm and cold stimulus easily by controlling the current flowing. While the magnitude of current determines the rate of change (ROC) of the thermal stimulus, the direction of the current dominates the direction of the heat transport, which leads to a cold or warm stimulus on one side. By controlling the current applied, one can achieve the desired thermal stimulus.

Peltier elements can be characterised by a model. The following three effects are subject to this model [31]

Qp - Peltier effect
Heat transport from one side to the other.

QRth - Heat backflow
Heat flow from the hot side to the cold side.

Rv - Joule heating/losses QRv represent in the resistance
The heat generated by **Rv** is equally divided between the hot and the cold side. The heat generated at the hot side is dissipated by the heatsink. If the heat is released sufficiently, it is not included in this equation.

The resulting pumped heat load **Qc** depends on three effects **Qp**, **QRth** and **QRv**. In the case of cooling, the equation for **Qc**. is as follows: **Qc = Qp-QRth-QRv**. As for heating, **Qc = Qp-QRth(+QRv)** (whether involving **QRv** or not depends on the efficiency of heat dissipation.)

Since the Peltier element is a current-oriented device, understanding the relationship between its efficiency and current is important. The efficiency of the Peltier element is defined by the COP. The definition of the COP is the heat absorbed at the cold side Qc divided by the input power Pel of the Peltier element: COP = QC / Pel. The COP is in principal the efficiency of the Peltier element when cooling [31]. The following diagram (Figure 23) shows the performance (COP) versus the current ratio I/ Imax, the values in this diagram are relative and normalized. From the diagram, the COP maximum depends strongly on the temperature difference (dT) between the warm and cold side. And it can be seen the COP maximum shifts towards higher currents when the dT is increasing. The COP doesn't start at zero with a dT > 0K. It is because the heat backflow QRth must be compensated by the Peltier effect Qp before the Peltier element cools.

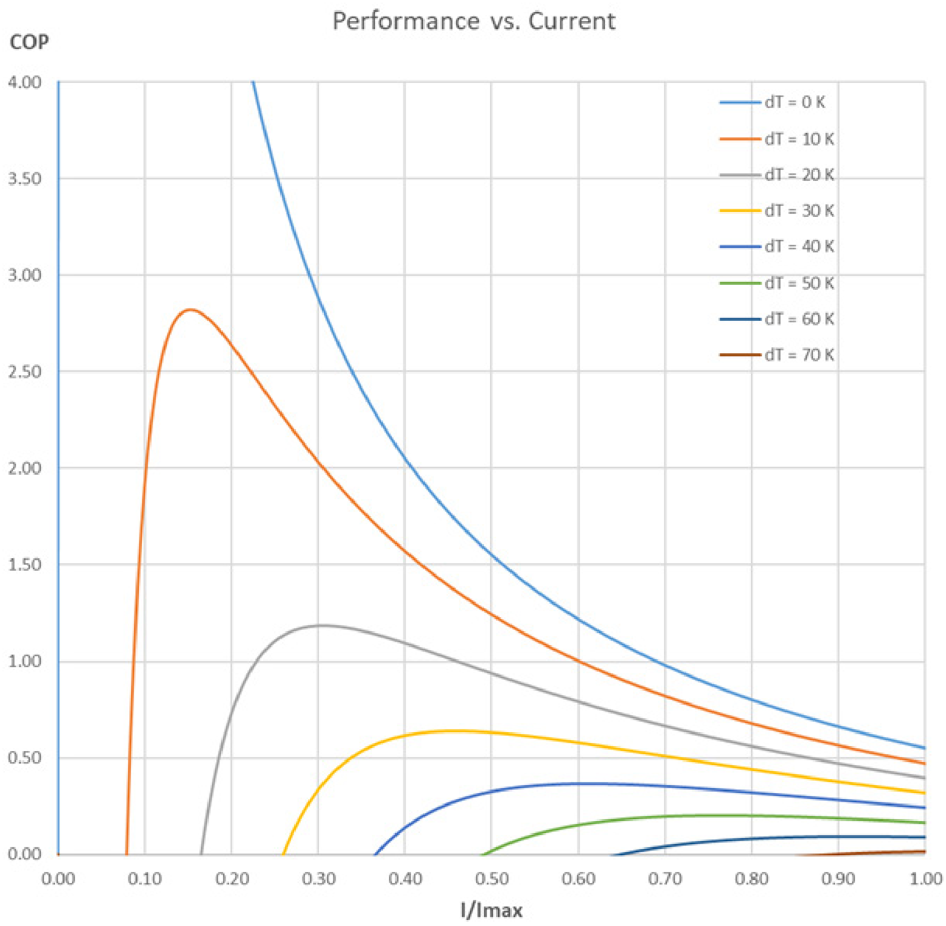


Figure 23. COP vs Current (from meerstetter engineering)

Knowing the characteristics of the Peltier element is crucial to design a prototype since the features bring specific requirements for building a precisely operating device. The difficulties encountered and solutions used for prototyping are explained in the following parts of this chapter.

5.2 Demo version

During the experiment one, participants will experience thermal stimulus with four conditions on the upper chest. For the experiment two, participants will experience the stimuli determined from study one on the upper chest. An armband which offers thermal stimulus was built as the demo version of the prototype (Figure 24). The device consists of two parts: 1). the armband; 2). the Peltier element with a control circuit. PID control is used to get a constant temperature.

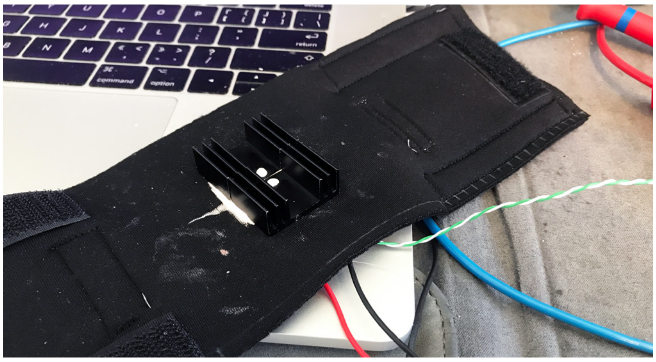


Figure 24. Demo version: the armband

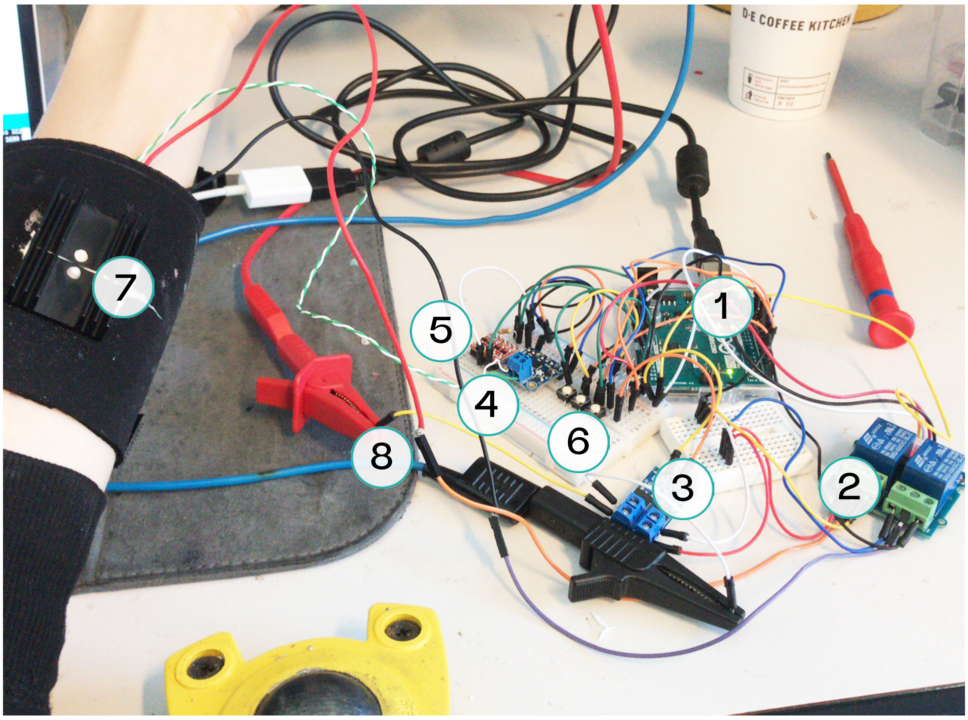
Figure 25-26. Switching between 'with silk' and 'without silk' mode by attaching the silk to the inner side or the outer side of the armband

Armband

The main structure of the armband is made of a piece of thick stretchy fabric. Hooks and loops are sewed to the band, which enables people to strap the band around their arms tightly. The silk is sewed on the inner side of the armband with one edge. The other edge can be attached to either the inner side or outer side of the band with hooks and loops (Figure 25-26). When placed on the inner side, the silk can cover the Peltier element and participants can feel the stimulus through the fabric.

Control circuit

The control circuit (Figure 27) consists of an Arduino board, a thermocouple, a Mosfet, a relay and four buttons. The thermocouple reads the real-time temperature of the touching area. The PID control in the program calculates the output value based on the difference between the Setpoint temperature and the real-time temperature. The MOSFET enables a wide range of output value. The relay controls the direction of the current flowing into the Peltier element, which determines if the stimulus is warm or cold. The four buttons refer to four thermal conditions (high intensity warm, low intensity warm, high intensity cold, low intensity cold). The Peltier element is powered by a 9V power supply through Mosfet. Figure 28 illustrates the circuit diagram. The detailed information of the elements used can be found in Appendix.



1 - **Arduino Uno**

2 - **Relay**

3 - **Mosfet**

4 - **Thermocouple**

5 - **Level convertor**

6 - **Buttons**

7 - **Peltier element attached to heat sink**

8 - **Power supply**

Figure 27. The control circuit of the demo version

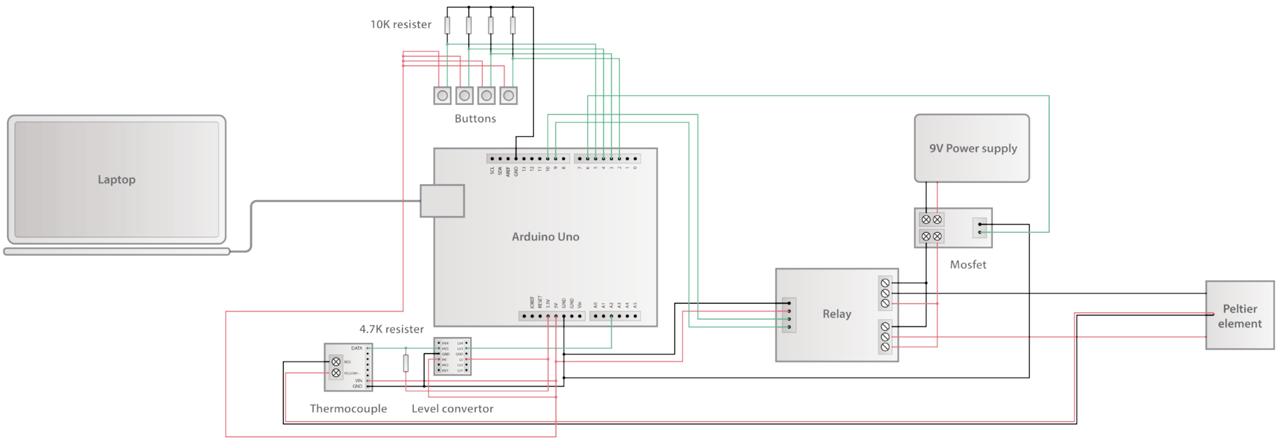


Figure 28. The diagram of the control circuit

PID control

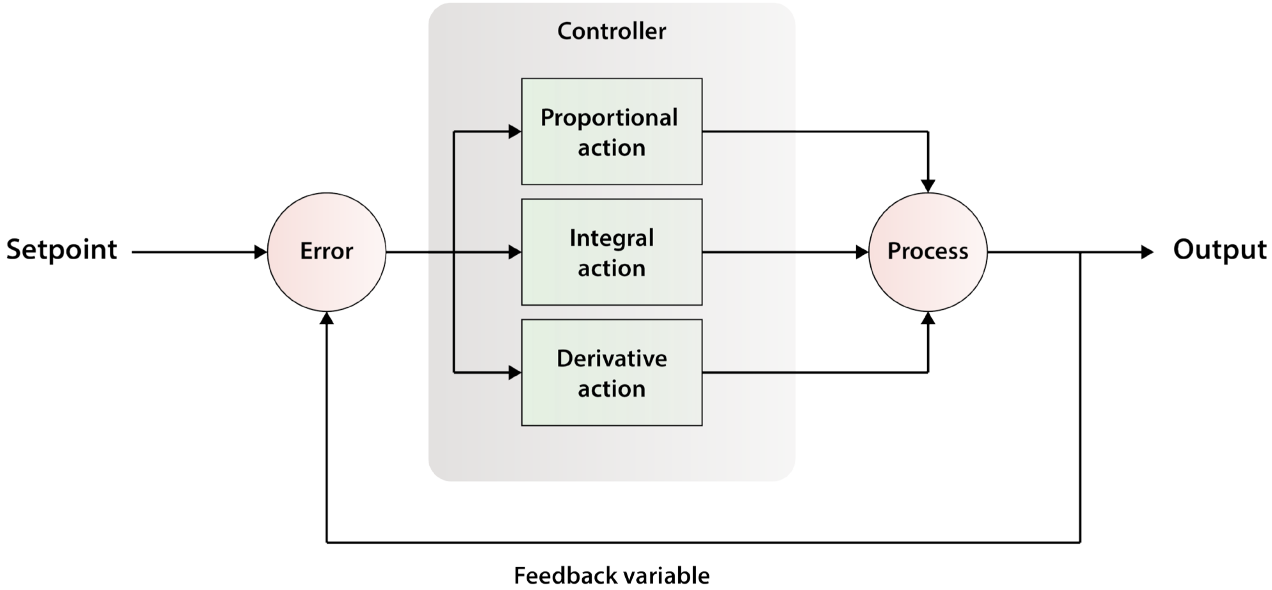


Figure 28. The workflow of PID controller

PID is a control loop feedback mechanism widely used in industrial control systems to achieve a continuously modulated control. A PID controller continuously calculates an error value as the difference between the desired setpoint and a measured process variable and applies a correction based on proportional, integral, and derivative terms (denoted P, I and D respectively) [32]. Figure 29 illustrates the workflow of PID control. Among the three terms, P determines how much the output value can be. The higher P value is, the higher the output value is. However, the output value can never reach the Setpoint only with P. By increasing I value, the output value can go over the Setpoint and achieve an oscillation around the Setpoint. By increasing D value, the oscillation will go away but it takes more time for the device to reach the Setpoint. For the prototype, I need a quick temperature change and a frequent Setpoint shift, therefore, D value is better to be zero. Only P and I need to be tuned.

Limitations of the demo version

The demo version was built to explore the techniques needed to realize basic functions (e.g., changing the temperature from baseline to the target temperature). To conduct the formal experiment, many parts of the prototype need updates. For example, the relay module made noise every time the current changed the direction, which might bring interference on people's emotional experience other than thermal stimulus. To have counterbalanced and randomized trials, the different conditions of thermal stimulus need to be generated randomly. This requires a program which can generate numbers randomly instead of pressing buttons manually. For the later analysis of the quantitative data, it's better to record the participants' ratings through a program than letting them write on paper. To meet the requirements of experiment one, a new system was developed out of the demo version. Besides, during the experiment, the thermal stimulus will be placed on human's upper chest. Therefore, the next prototype will integrate the Peltier element on the upper chest of the clothes.

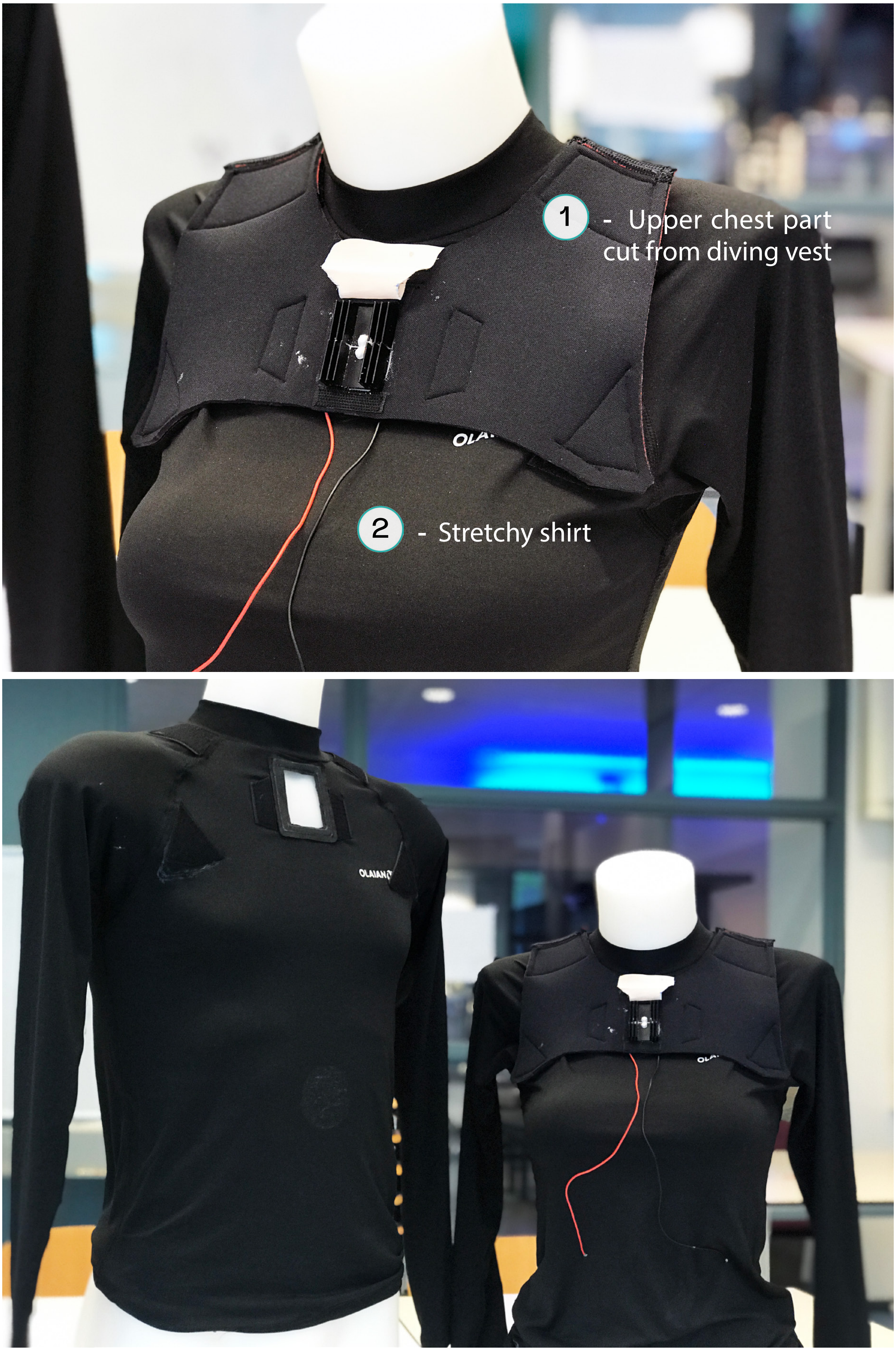


Figure 30. Prototype: the clothes part

5.3 Prototype for experiment one

For experiment one, the participant should experience thermal stimulus with four conditions on the upper chest through the fabric and naked skin and give their feedbacks. A system was built to experiment. The system consists of two shirts (male version, female version) with a control circuit, an Android application and a monitoring window on the laptop.

Clothes

Two clothes (a male version and a female version) with the Peltier element offering thermal stimulus on the upper chest are built (Figure 30). They were built with two stretchy shirts and a diving vest. The upper chest part of the vest was cut out and used to place the Peltier element. The vest was thick enough to hold the element without shape change. I cut a hole in the middle of the vest. The Peltier element and the heat sink is connected through the hole with thermal glue. The Peltier element is embedded on the inner side, while the heatsink is attached on the other side. A piece of silk was sewed on the vest and can cover the Peltier element if needed. For the shirt, a front opening was made, through which, the Peltier element can touch the skin on the upper chest. The vest and the shirt are connected with hooks and loops. The hooks and loops were sewed on the shoulder, the lower sides of the chest and right next to the front opening (Figure 31). One problem encountered was that the opening on the shirt would have shape change if it was put on a relatively huge person. To solve the problem, I sewed an aluminum frame on the edge of the opening so the structure is stable even if the shirt is stretched (Figure 32). In this way, the shirt is suitable for multiple sizes.

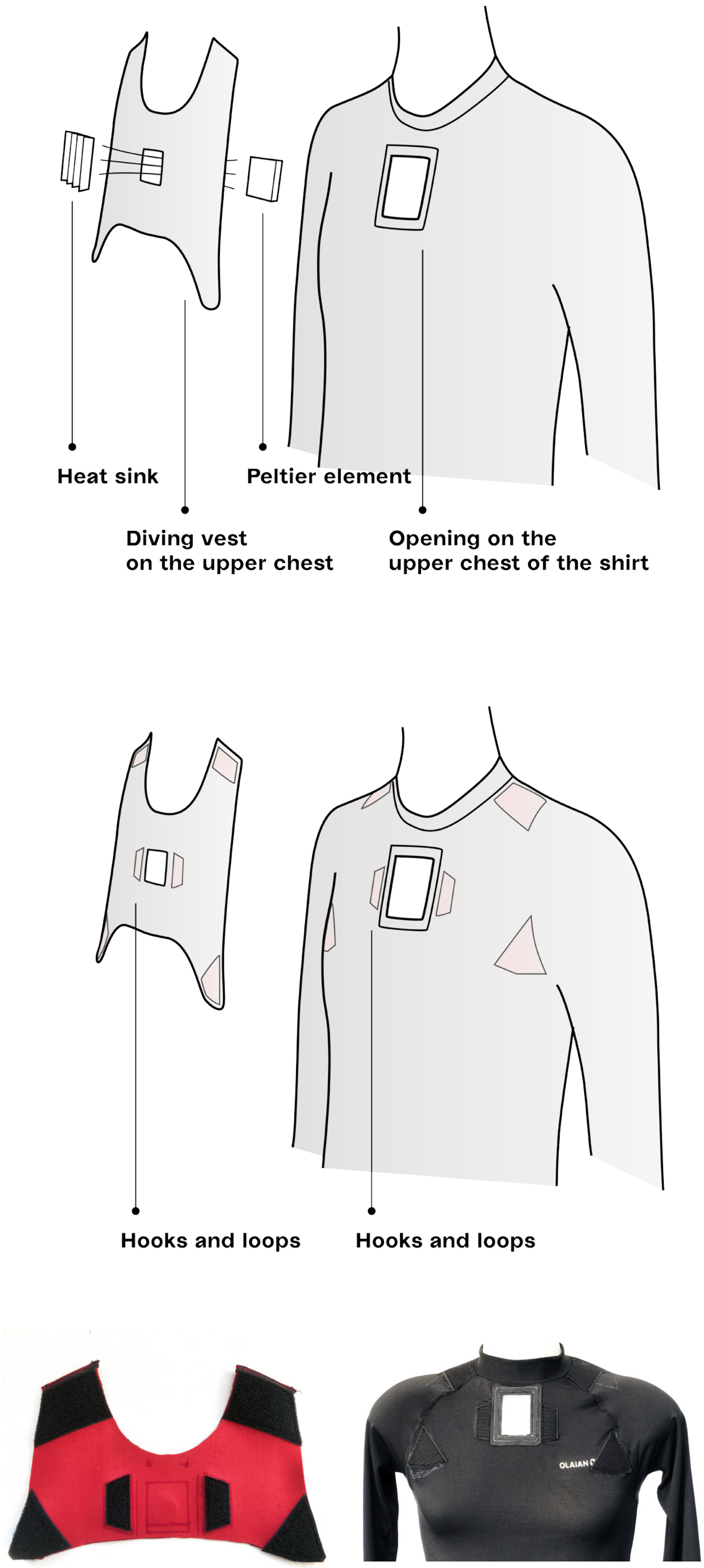


Figure 30. The structure of the clothes

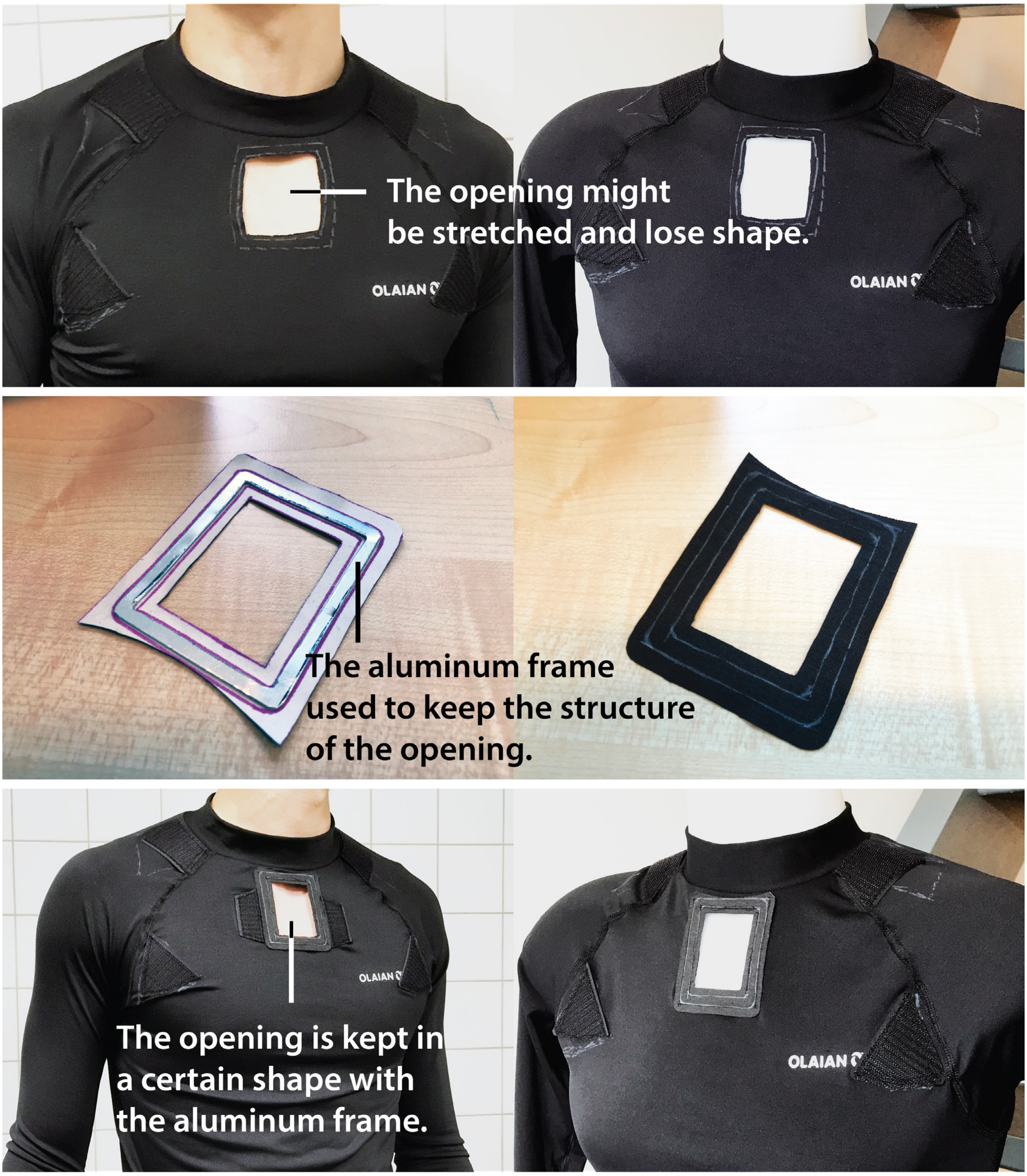
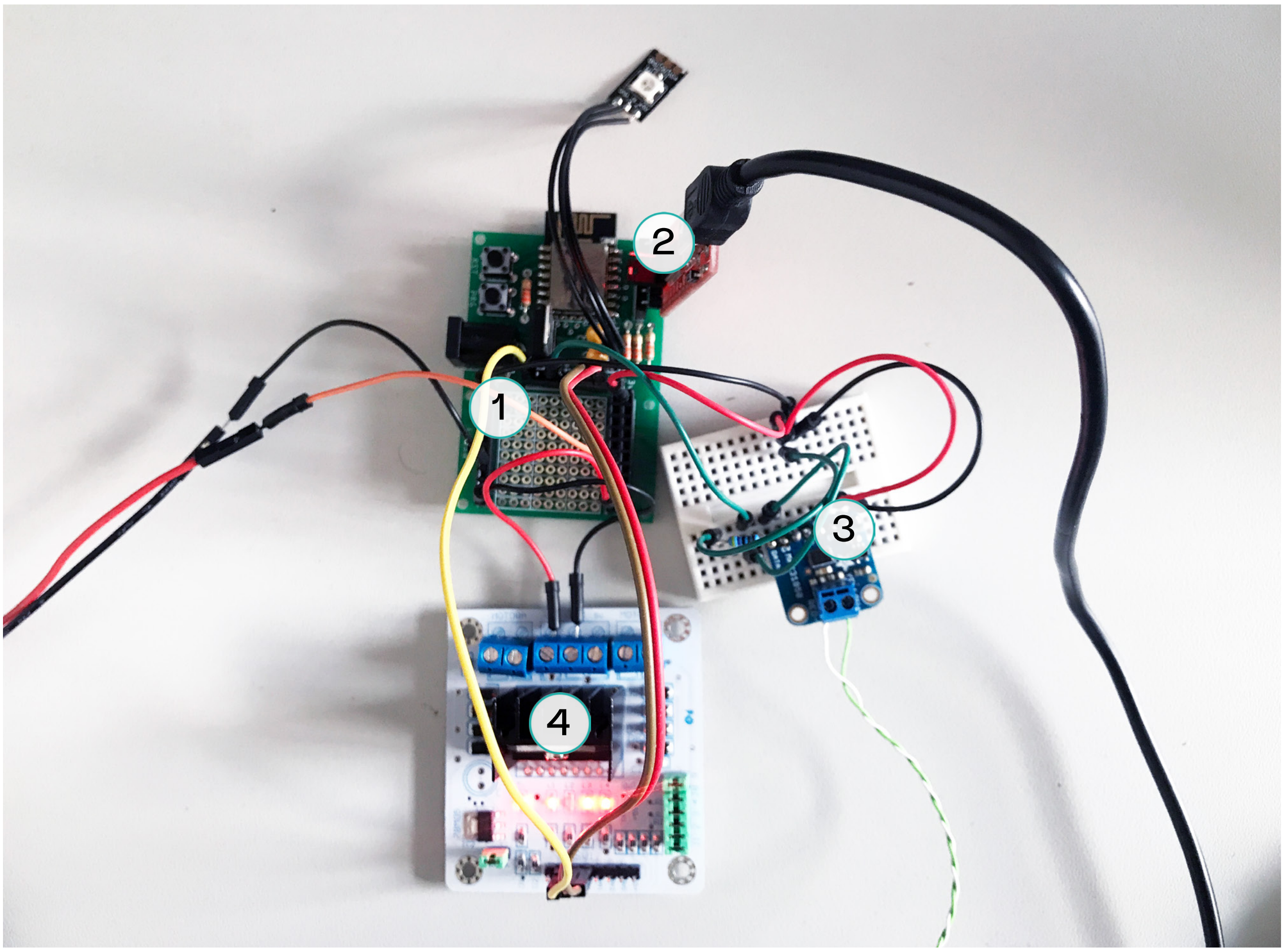


Figure 32. Using an aluminum frame to hold a stable structure of the opening

Figure 33. Prototyping

Figure 34. The clothes fit different sized people

Control circuit

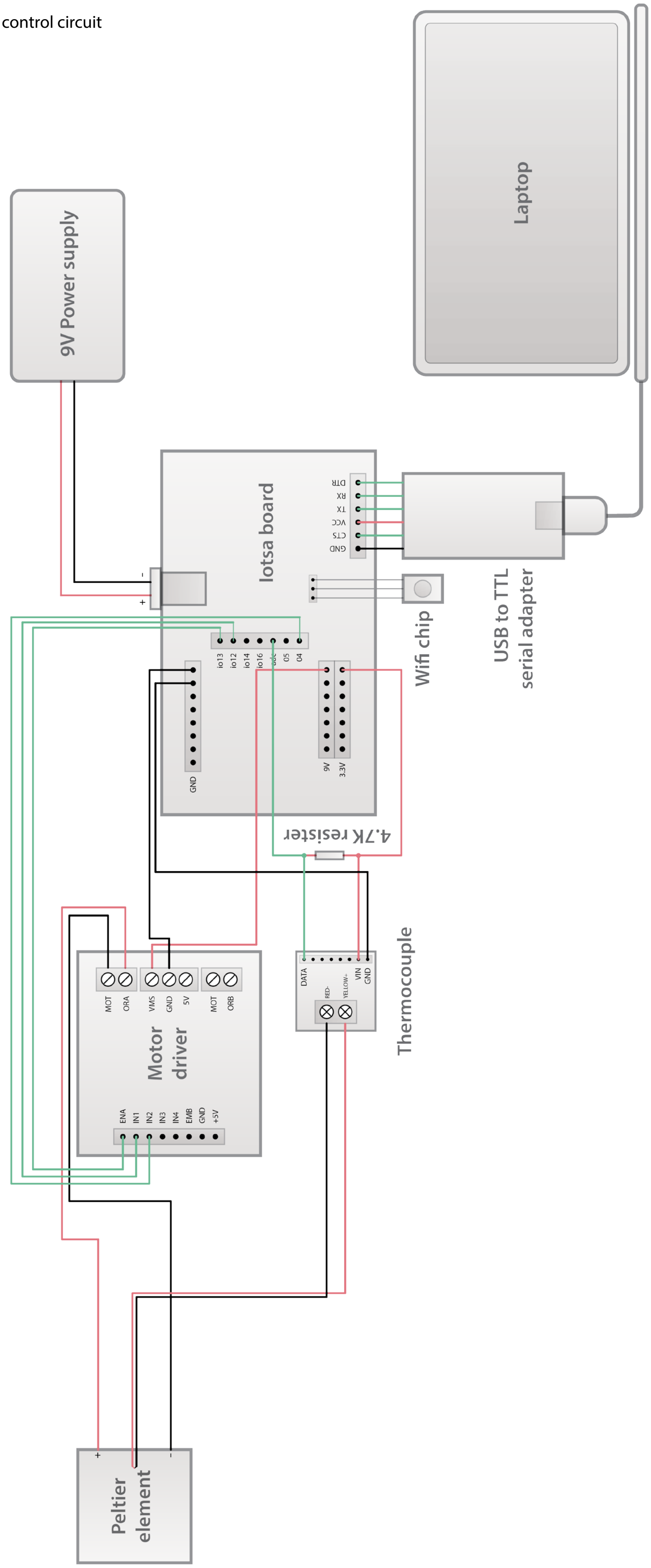


1 - Iotsa board **2 - USB to TTL serial adapter** **3 - Thermocouple** **4 - Motor diver**

Figure 35. The control circuit for experiment one

The control circuit consists of a Iotsa board, a thermocouple, a motor driver and a USB to TLL serial adapter (Figure 35). The Iotsa board is the microcontroller of the system, which communicates to the phone and the laptop via wifi. The physical board and the program library [33] is built by Jack, a colleague from CWI. It receives the commands from the smartphone and regulates the output value added to the Peltier element. The thermocouple records the real-time temperature of the touching area and sends it to the Iotsa board. The PID control in the program calculates the output value based on the difference between the Setpoint and the real-time temperature. The motor driver enables the change of output value in terms of the voltage and direction to offer different thermal stimuli. Through the serial adaptor, the real-time temperature can be monitored from the terminal window on the laptop. Compared to the demo version, fewer components are used, which keeps a more simple circuit. Besides, the motor driver doesn't make noise when the current changes direction. Therefore, no acoustic disturbance from the circuit would affect emotion perception during the second experiment. Figure 36 illustrates the circuit diagram. The detailed information of the elements used can be found in Appendix.

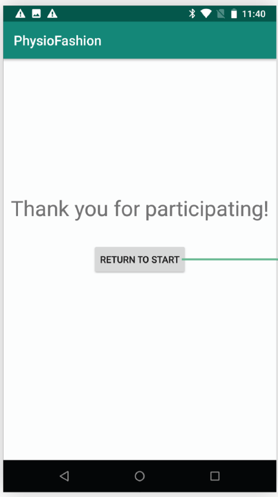
Figure 36. The diagram of the control circuit



Android application

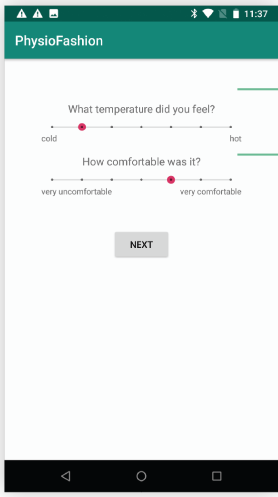
During the experiment, the participants were guided to complete the task by an Android application. The application was developed by Thomas, another colleague from CWI. The application sends the command to the Iotsa board and records the basic information and feedback from participants. The participants input their basic information (the participant ID, the counter number, if the fabric is on) on the first page. Afterward, they experience the thermal stimuli and offer feedbacks with the guidance of the application. The application can generate Setpoint temperature randomly so the sequences of the thermal conditions are randomized. Participants' ratings of thermal intensity, comfort and detection time are collected by the application and saved as CSV. file. Figure 37 shows the process of the application.

Final step/ Start over
Enter the final page after finishing all the eight stimuli.



Go back to the login page to start the second part (with or without fabric)

Step2 Again
Enter the round for the second thermal stimulus

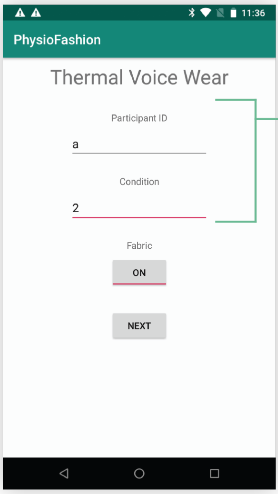


From "cold" to "neutral" to "hot"

From "very uncomfortable" to "no difference from no thermal stimulus" to "very comfortable"

Step1/ Basic info.

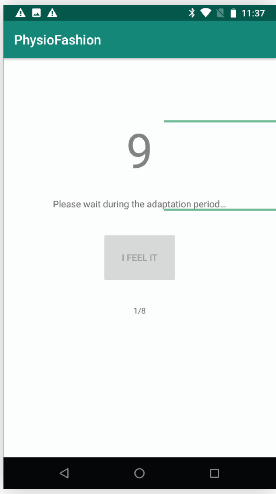
Input participant ID, the number of the first thermal condition and if the fabric is on or off.



Fill in basic info.

Step2/ Adaptation

Adapt your skin temperature to the baseline temperature of 32°C. The adaptation lasts for 10 seconds.

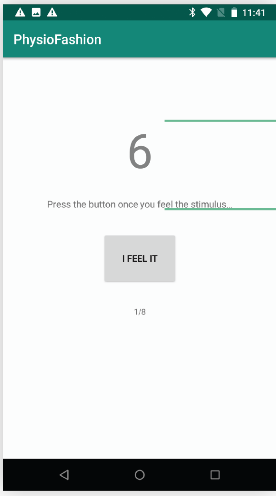


The countdown of the adaptation duration

The button is used to record the moment people start to feel the thermal stimulus. The button is unclickable in the adaptation phase.

Step3/ Experiencing thermal stimuli

The thermal stimulus is added for 7 seconds from the baseline temperature (32°C).

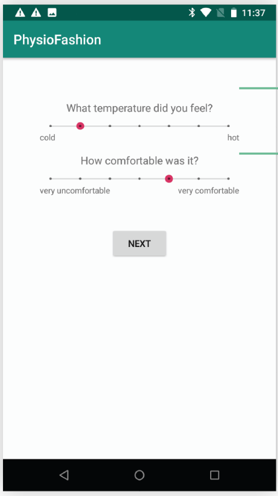


The countdown of the thermal stimulus duration

The button is used to record the moment people start to feel the thermal stimulus. The button is unclickable in the adaptation phase.

Step4/ Ratings

Input your ratings in terms of the intensity and comfort of the thermal stimulus.



From "cold" to "neutral" to "hot"

From "very uncomfortable" to "no difference from no thermal stimulus" to "very comfortable"

Figure 34. The workflow of the application - version for experiment one

5.4 Updating prototype

The prototype was tested after all the parts were connected. Some adjustments are made based on the test. These adjustments are mostly due to the characteristics of the Peltier element.

Characteristics of Peltier element

Although, Peltier element is the most common thermal output device, achieving a precise thermal stimulus is not easy. Because of the heat backflow(QRth) (Figure 38) and the generated heat(QRv) (Figure 39), the cooling efficiency of the Peltier element is always lower than that of heating. QRv affects not only the cooling efficiency but also the overall performance. Since QRv increases the overall energy inside the element, which refers to the baseline temperature, as time going on, reaching the cold target temperature gets more difficult while reaching the warm one gets easier.

The characteristics bring some negative effects on the experiment. The baseline temperature during the experiment is 32°C, which is roughly the temperature of the touching area when there is no heat transfer between Peltier element and human skin (in the room of 23°C). With the experiment going on, the heat is continuously generated inside the element. To maintain a constant 32°C on the touching side, the heat is moved to the other side almost from time to time. Although a heat sink is used for dissipation, The temperature difference(dT) still increases, which causes a low efficiency(COP). With the same PID parameters and applied voltage, heating gets easier while cooling gets more difficult. Therefore, the ROC will change a little bit. In general, the ROC for cooling will decrease while the ROC for heating gets higher. If the experiment takes too long and dT gets too high, the element even has difficulty reaching the cold target temperature. Besides, because of QRth, a certain range of low output value doesn't work for the Peltier element's cooling (Figure 40).

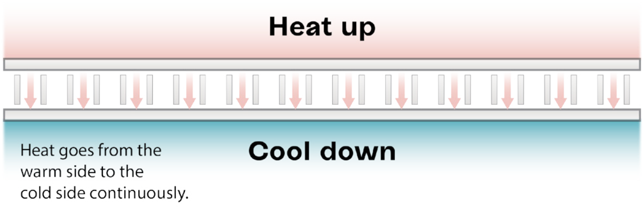


Figure 35. QRth: the heat backflow

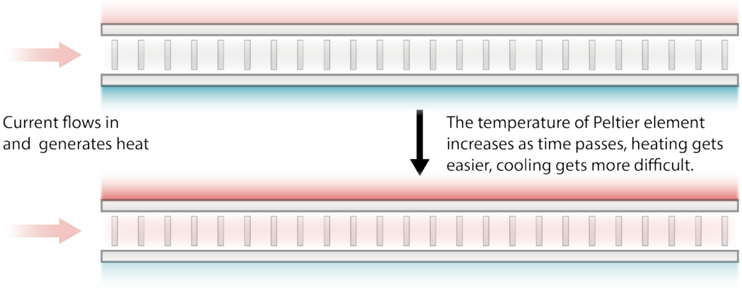


Figure 39. QRv: the overall temperature of Peltier element increases with the current flowing in and generating heat

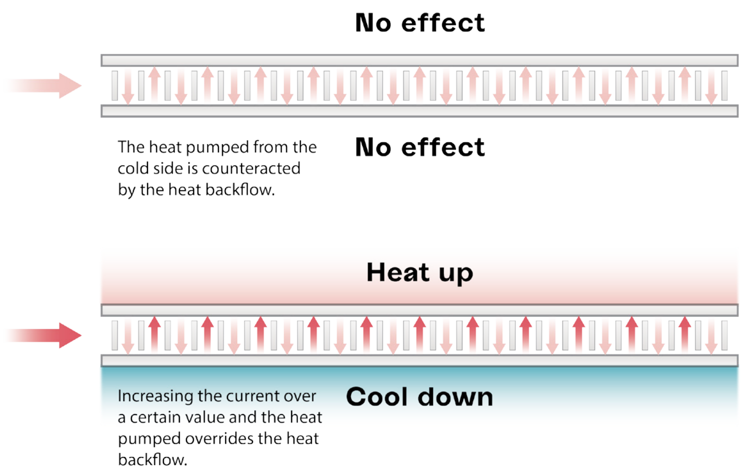


Figure 40. QRv: The cooling starts to work after the current is above a certain level

Updating prototype 1

To avoid the inefficient range of output value, I added a trick in the program. When the output is below a certain value, I set a settled output value instead of using PID calculation. Through some tests, I found that Peltier doesn't work when the output value is below around 200 (the full range is from 0 to 1023) with 7.5V. In the code, I chose 250 as the "intervention point". I set the output value to 250 when it is below 250. Therefore, the range from 250 to 1023 is the working output. After the adjustment, it worked fine when not attached to people's skin.

Besides, to get a relatively similar ROC for all thermal conditions, I set different PID parameters for different setpoints because of three reasons: 1) PID control is based on the error value between the real-time reading and the setpoint. Therefore, compared to high intensity, the lower intensity receives lower output value and leads to a lower ROC. To achieve a relatively close ROC, the P value for low intensity needs to be increased. 2) The COP of cooling is always lower than that of heating. Therefore, I set higher P values for cold setpoints. 3) Considering the isolation effect of fabric, to prolong the changing time when the fabric is added, the P value needs to be decreased.

Skin's effect on the device

When trying the device with myself, I found that the ROC gets lower and it can't reach the high-intensity temperatures anymore. It might be caused by the fact that the specific heat capacity of skin is much higher than air. When heating, the heat is absorbed by skin immediately. When cooling, the heat goes from skin to Peltier element much faster compared to air. If we define the heat transferred between the Peltier element and skin as Qsp. Then, to offer the same cold temperature, the heat pumped is as: Qp=Qc+QRth+QRv+Qsp.

For heating, it's as: Qp=Qc+QRth-QRv+Qsp. Therefore, when touching people's skin, it needs a higher output value to keep the ROC and finally reach the high-intensity temperatures.

Updating prototype 2

To increase the ROC, I tuned the PID parameters again to get a higher output value. After several attempts, with the I value always being 2 and D value being 0, I got the following P values for the four setpoints:

Without fabric:

P = 180 (Setpoint = 35)
P = 100 (Setpoint = 38)
P = 280 (Setpoint = 29)
P = 200 (Setpoint = 26)

With fabric:

P = 180 (Setpoint = 35)
P = 90 (Setpoint = 38)
P = 280 (Setpoint = 29)
P = 160 (Setpoint = 26)

However, because of the higher current and the heat from the skin, the Peltier element got hot faster and the heat could not be dissipated in time with the heat sink. Previous research usually attaches a fan to the heat sink for better heat dissipation (Figure 41) [23] [36]. However, the fan would cause noise and vibrations when working. Considering that this is an experiment focusing on thermal's effect on emotion perception, other modalities should be shielded as much as possible.

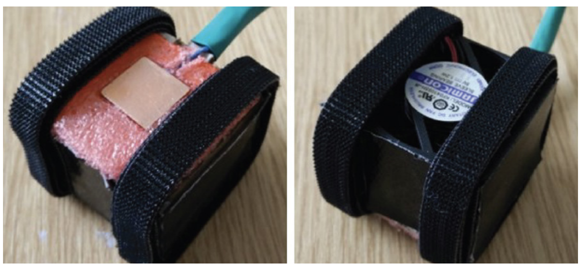


Figure 41. A fan attached to the Peltier element

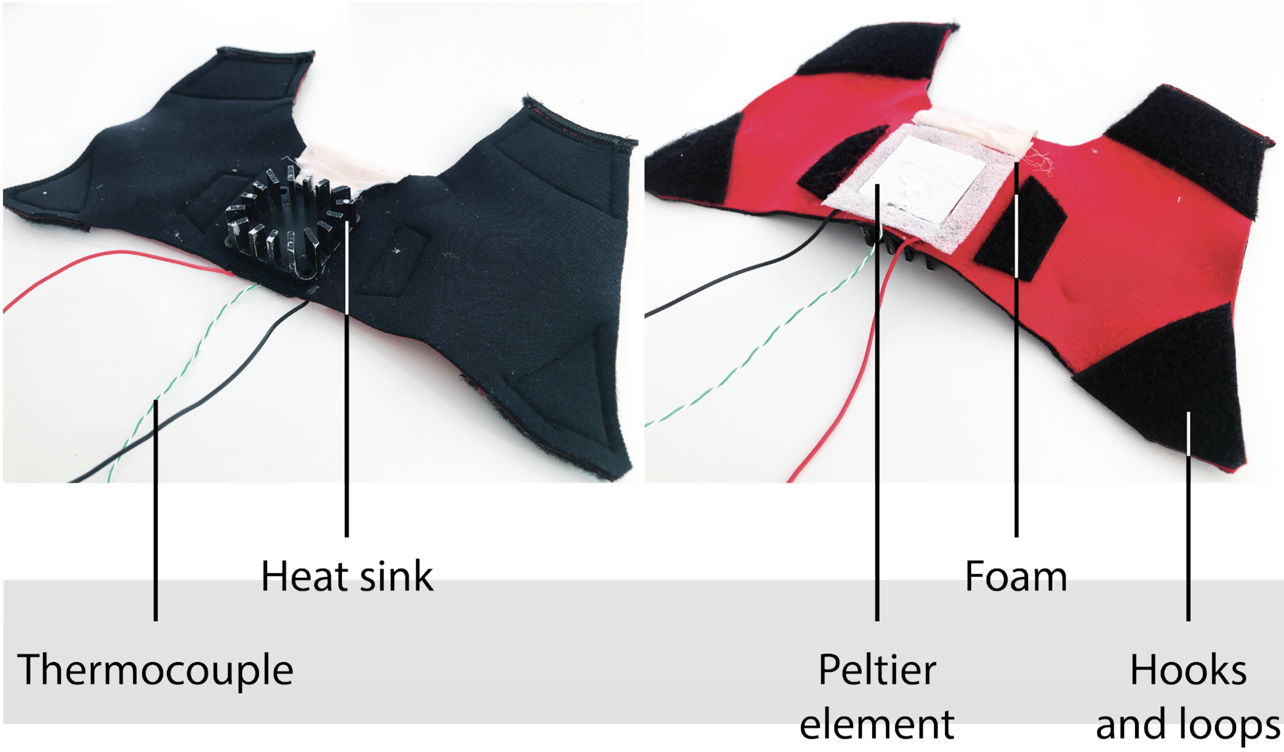


Figure 42. The vest part with Peltier element and a bigger heat sink

To still keep a low dT, the decision is to switch the heat sink to a bigger one and add a short break in the middle of the experiment to cool the Peltier element down. Figure 42 shows the final form of the vest part.

Because of the higher dT, the inefficient range of output value gets wider when it's heating or cooling. Therefore, I tried the device on myself to find "intervention points" for every setpoint (Figure 43). After several attempts, I set 300 for Setpoint 35°C and 400 for Setpoint 38°C. 700 is used for Setpoint 29°C. As for Setpoint 26°C, 700 is applied for the no fabric condition while 650 is used when the fabric is added.

I had a pilot test with a participant using the tuned system. The ROC was lower than what it was when tested on me. This reveals the fact that Qsp is highly determined by the individual. Lots of factors like skin conditions, the attaching condition of Peltier element will affect it. Increasing the power supply might help but the higher current will shorten the high-efficiency working time. Besides, thermal perception is based on the heat flowing in or out of the skin, not directly based on the temperature of the touching object. Therefore, it's reasonable to accept the different ROC performance on different people and regard it as normal behavior of the system when used across massive users. As a trade-off, I increased P value a little bit and added a break in the middle of the experiment to cool down the Peltier element.

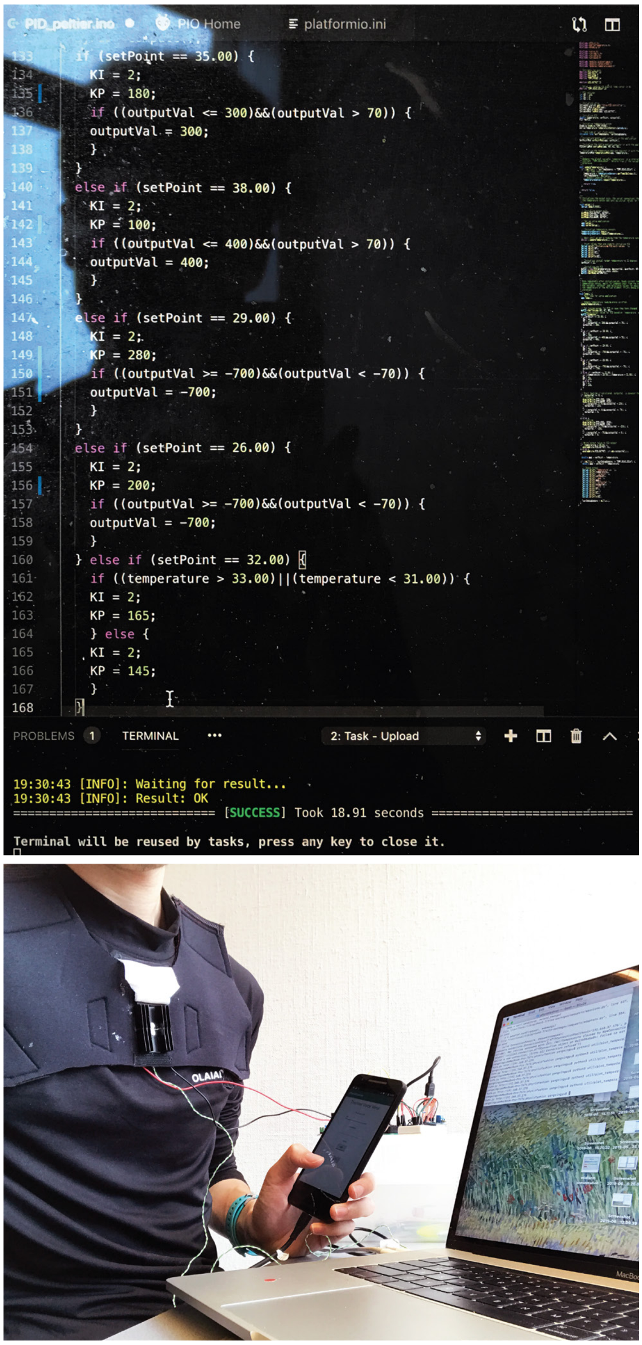
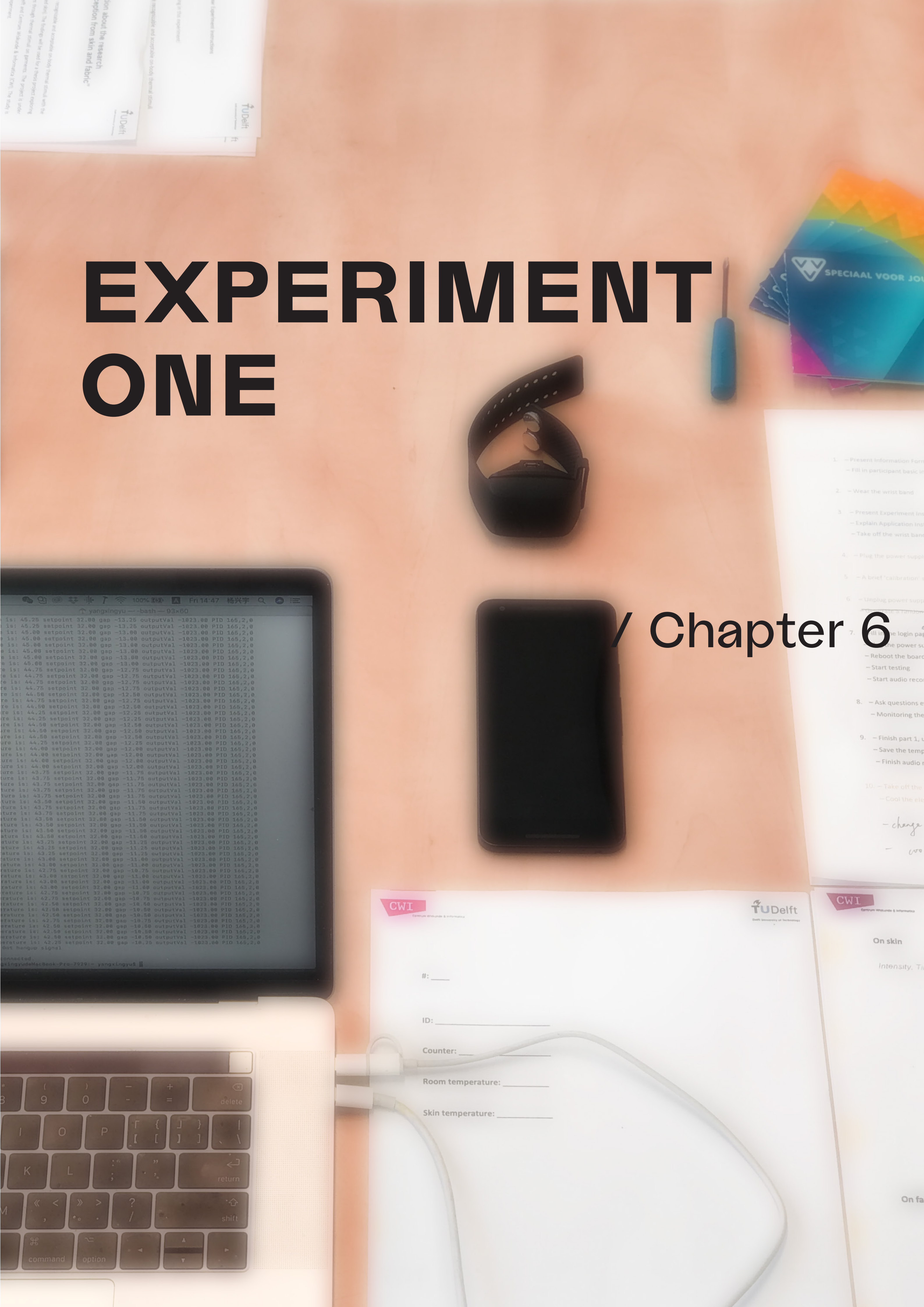


Figure 43. Testing with myself to tune the device

EXPERIMENT ONE

/ Chapter 6



Introduction

The purpose of this study is to find the recognizable and acceptable on-body thermal stimuli with a suitable contact medium (fabric or naked skin) in the context of remote communication through voice message. During the experiment, four thermal stimuli (warm high intensity, warm low intensity, cool high intensity, cool low intensity) were added on the upper chest of the participants through the fabric and naked skin. Participants' ratings of subjective intensity and comfort, as well as time to detect the stimulus, are collected for analysis.

6.1 Setup

1 - **Shirt for experiment**
2 - **Iotsa board**
3 - **Peltier element**
4 - **E4 wrist band**
5 - **Voucher**
6 - **Thermometer**
7 - **Smart phone**
8 - **Paper forms**
9 - **Laptop**

Figure 44. Experiment setup

The experiment was conducted in a room of 23°C. The control circuit, the Android application, and the laptop were connected through wifi. Paper forms including experiment instruction, consent form, participant information form, and application instruction were offered on the table. The real-time temperature of the touching side of the Peltier element was monitored through a window on the laptop. A thermometer was used to measure the room temperature. An Empatica E4 wristband was used to collect the skin temperature of the participant before the experiment. The setup of the experiment is shown in Figure 44. 12 participants (six males, six females) were invited for the experiment. They are researchers from CWI and master students from TU Delft.

6.2 Process

Figure 45. Prticipants performing tasks in experiment one

Participants were first welcomed and led to read and sign the paper forms. At the same time, their skin temperature was collected by the E4 wristband. Afterward, they put on the clothes with Peltier element on the upper chest and received a calibration session. During the session, they got familiar with the thermal stimuli and application by experiencing the coolest and warmest stimuli.

Afterward, the main part of the experiment started. Participants experienced 16 trials including four thermal conditions (Figure 45). Eight of them were experienced through naked skin, the other eight were experienced through a piece of silk. Each stimulus lasted for seven seconds. There was a two-minute break between the two parts. Each condition was presented twice. The sequence of the stimulus was randomized. The first condition was counterbalanced across participants. Before every stimulus, there was a ten-second duration to adapt the temperature of the touching area to the baseline of 32°C. In the period of the seven-second stimulus, the participant would press 'I feel it' button once they felt the stimulus and the application would record the time used to detect the stimulus. After experiencing each stimulus, the participant gave feedback in terms of intensity and comfort on the phone application. Figure 46 shows the temperature change of the touching area during the experiment.

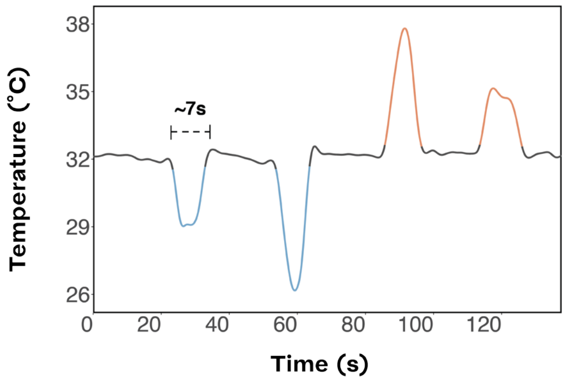


Figure 46. Temperature change of the touching area

Throughout the process, they were encouraged to think aloud about their feelings in terms of thermal sensation and comfort. Figure 47 illustrates the process of the main tasks. After going through all the trials, a short semi-structured interview was conducted. They were asked to recall the stimuli experienced and talk about the difference they felt between different conditions. They were also encouraged to give open feedback. The whole process was recorded by an audio recorder. After the interview was over, they were rewarded with a 10 euro voucher. The whole process took around 45 minutes.

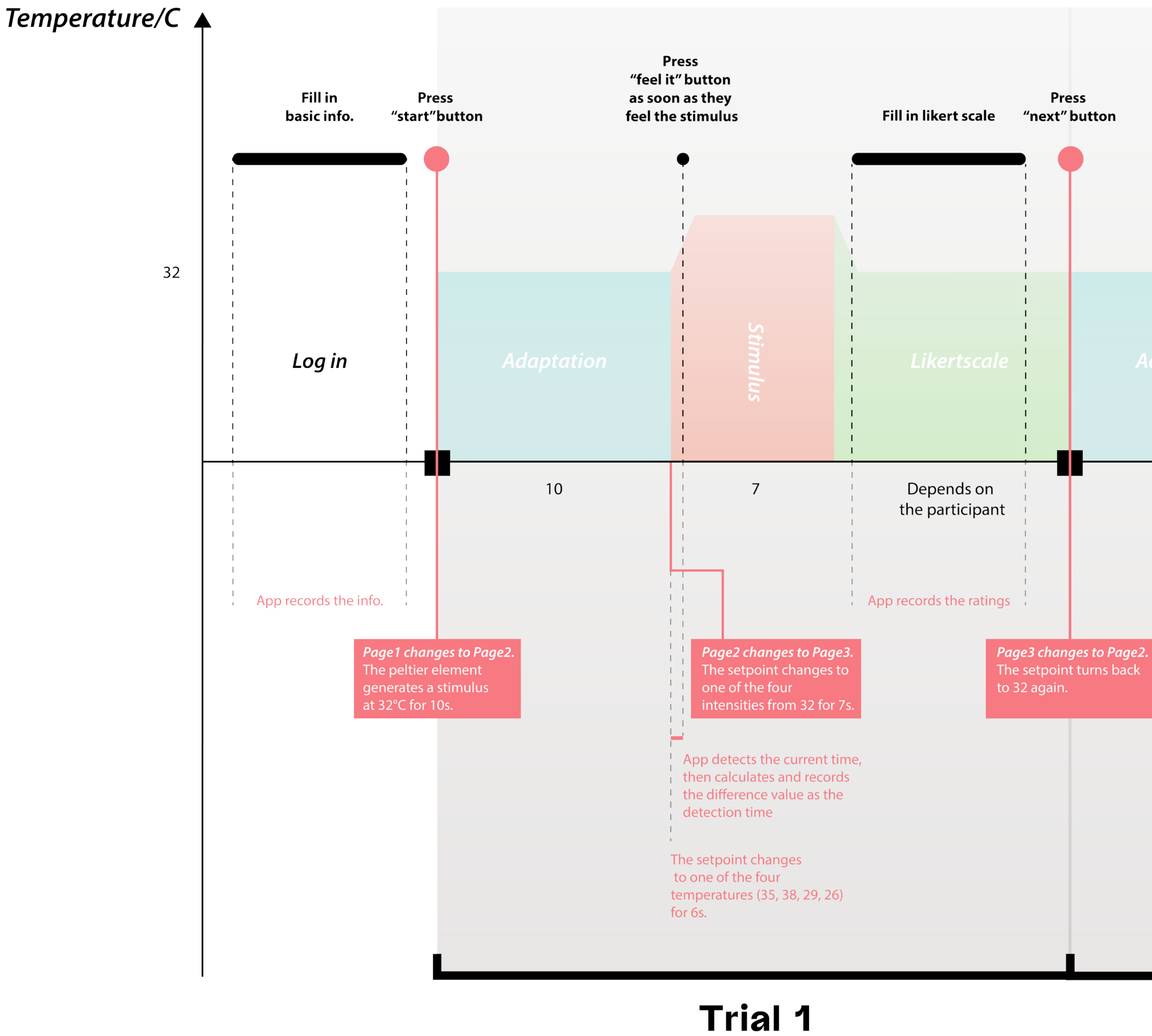
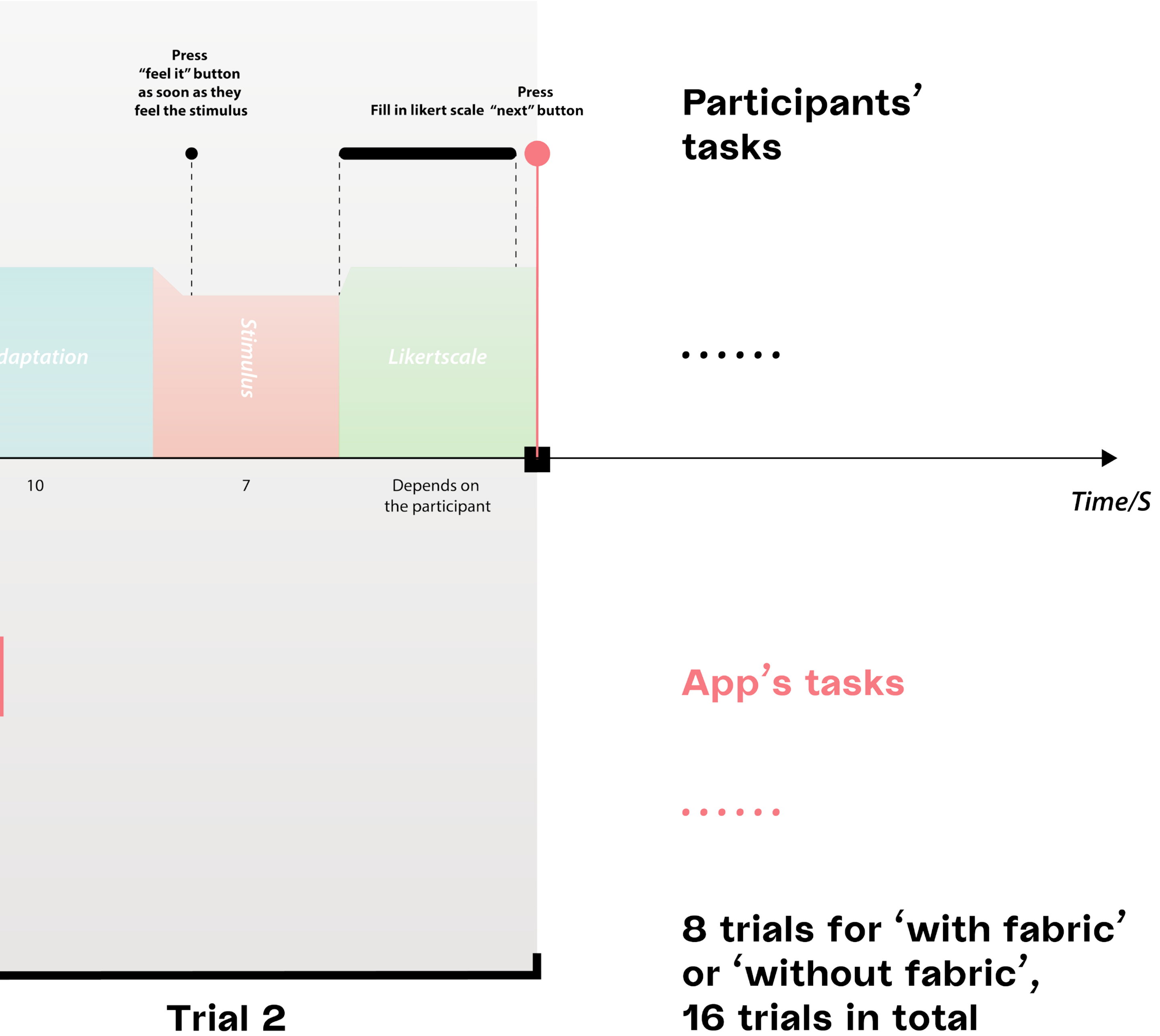


Figure 47. Process of the main task



Participants' tasks

• • • • • •

App's tasks

• • • • • •

8 trials for 'with fabric' or 'without fabric', 16 trials in total

6.3 Result analysis

The results collected from 12 participants were analyzed in RStudio. The median value of subjective intensity, subjective comfort and time to detect the stimulus was computed.

From the quantitative result, people, in general, can feel the different intensities for both cold and warm stimulus when it's added on naked skin. The comfort level between high and low intensity doesn't have a universal pattern across the participants. Adding a piece of silk weakens the subjective intensity of the stimulus, prolongs the detecting time but doesn't increase the subjective comfort. For the cold stimulus, the silk makes it difficult to tell the difference between high and low intensity.

However, the perception of thermal stimuli is very different across individuals. Therefore, the quantitative results are followed by qualitative feedback collected from participants' thinking aloud and the semi-structured interview. The qualitative result serves as a supplement which adds more details about an individual's perception of the thermal stimulus. The complete qualitative feedback with the profile information of each participant can be found in Appendix.

Subjective intensity

Box plots for perceived temperature ratings for warm and cold stimuli across contact medium and thermal intensity factors are shown in Figure 48 and Figure 49 respectively. The horizontal lines within each box represent the median, the box bounds the Inter-quartile (IQR) range, and the whiskers show the max and min non-outliers. The dashed line indicates the mean line across conditions. Shapiro-Wilk normality tests showed that participants' warm ($p<0.001$) and cool ($p<0.001$) ratings are both not normally distributed. Therefore, non-parametric statistical tests was conducted.

- Warm stimulus

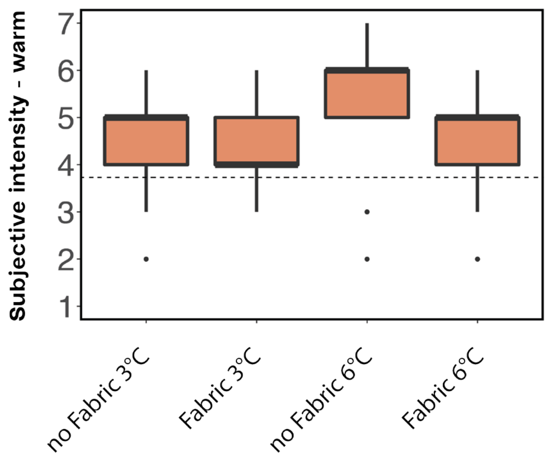


Figure 48. Box plots of subjective intensity of warm stimulus

Comparing four matched groups within subjects, a Friedman rank sum test is performed. A significant effect of thermal intensity and contact medium conditions on warm temperature ratings (c2(3)=22.2), $p<0.001$) is found. A post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences only between noFabric 6°C and Fabric 6°C ($Z = -3.4$, $p<0.001$, $r = 0.5$) and between noFabric 3°C and noFabric 6°C ($Z = -3.2$, $p<0.05$, $r = 0.46$). These results indicate that concerning perceiving warm thermal stimuli, adding fabric influences perception only for the higher thermal intensity (6°C), and when there is no fabric medium, the difference between low and high thermal intensity becomes more visible.

- Cold stimulus

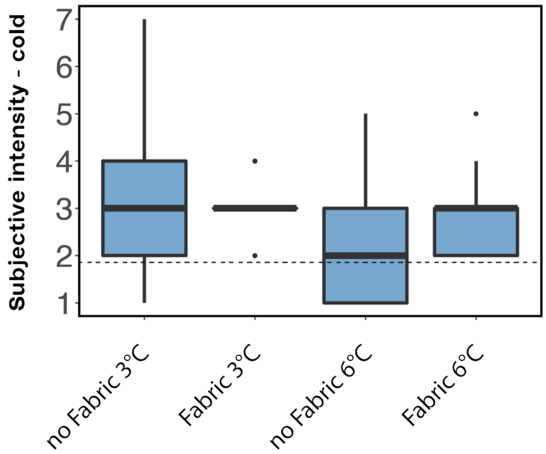


Figure 49. Box plots of subjective intensity of cold stimulus

Comparing four matched groups within subjects, a Friedman rank sum test is perfromed. A significant effect of thermal intensity and contact medium conditions on cool temperature ratings (c2(3)=12.5), p<0.05) is found. A post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences only between noFabric-6°C and Fabric-6°C (Z = 2.1, p<0.05, r = 0.31), between Fabric-3°C and NoFabric-6°C (Z = 2.4, p<0.05, r = 0.35), and between NoFabric-3°C and NoFabric-6°C (Z = 2.9, p<0.05, r = 0.41). These results indicate that with respect to perceiving cool thermal stimuli, adding fabric lowers cool stimuli perception for higher thermal intensity (-6°C), especially when added to lower thermal intensity (-3°C). Furthermore, when considering contact on the naked skin, not surprisingly, the higher thermal intensity is perceived to be colder.

- Qualitative feedback

Most people said that they were more sensitive to cold stimuli (P1, P3, P4, P7, P8, P9, P11, P12). While two participants said the warm ones were more detectable for them (P2, P10). Participant 2 even didn't feel any cold ones with fabric. Two participants said they had difficulty to tell the difference between high and low-intensity stimulus. Participant 8 explained that he couldn't tell the difference for the cold ones because both high and low intensities were too intense for him. In terms of the effect of fabric on subjective intensity, four participants (P2, P4, P5, P9) said it weakened the warm stimulus more than cold ones. They used "subtle" to describe the perception of warm stimulus through the silk. One participant (P10) felt nothing with fabric for both warm and cold stimuli.

- Summary

In general, participants can differentiate the four thermal conditions. Adding a piece of fabric decreases the subjective intensity for both warm and cold stimuli except for the low intensity cold. For the low-intensity cold, the result doesn't show a difference between "with fabric" and "no fabric" state. Besides, people are more sensitive to cold stimuli compared to warm ones, which is in line with the findings from previous research [29].

Subjective comfort

Box plots for perceived comfort ratings for Fabric and NoFabric across the direction of change and thermal intensity factors are shown in Figure 50 and Figure 51 respectively. Shapiro-Wilk normality tests showed that participants' fabric ($p<0.001$) and no fabric comfort ($p<0.001$) ratings are both not normally distributed. Therefore, non-parametric statistical tests was conducted.

- Fabric on

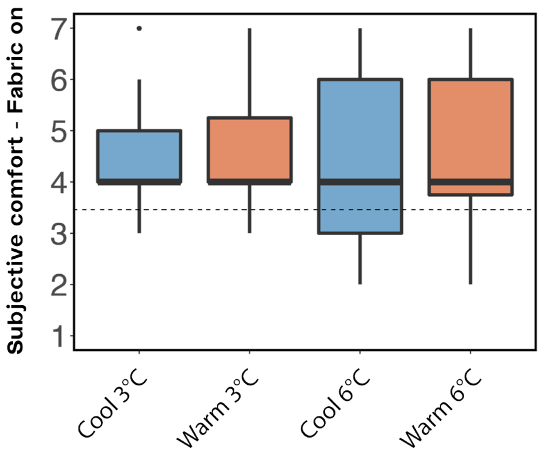


Figure 50. Box plots of subjective comfort of warm stimulus

Comparing four matched groups within subjects, a Friedman rank sum test is performed. However, we did not find a significant effect of thermal intensity and direction of change on Fabric comfort ratings (c2(3)=2.8), p=0.42). This indicates that participants found the thermal stimulation neither comfortable nor uncomfortable irrespective of fabric as a contact medium, given the uniform median ratings of 4 (IQR=2).

- Fabric off

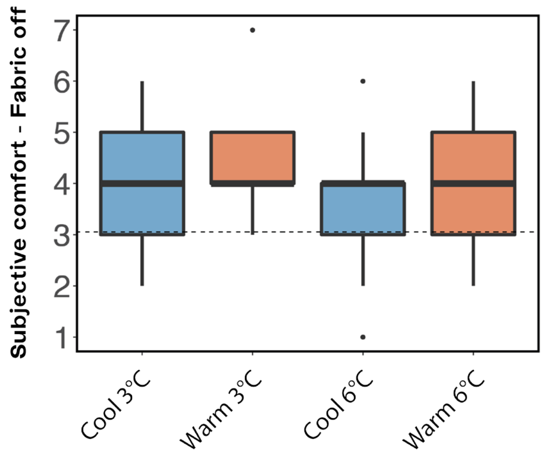


Figure 51. Box plots of subjective comfort of warm stimulus

Comparing four matched groups within subjects, a Friedman rank sum test is performed. Here as well, we did not find a significant effect of thermal intensity and direction of change on noFabric comfort ratings (c2(3)=5.5), p=0.14). This indicates that participants found the thermal stimulation neither comfortable nor uncomfortable irrespective of using skin as the direct contact medium, given the uniform median ratings of 4 (IQR=2)

- Qualitative feedback

For the subjective comfort, three participants (P2, P6, P11) mentioned the higher comfort level of low-intensity stimulus. Two participants (P4, P8) felt that the warm stimulus is more comfortable while participant 2 said the high intensity warm is too intense and might make him uncomfortable if added for a longer time. For the cold stimulus, participant 4 said that the cold one felt more comfortable. Two people (P2, P9) used "refreshing" to describe the feeling. However, participant 11 said the cold stimulus was too intense for her and the high-intensity stimulus even made her tremble a little bit. Although quantitative result shows that adding a piece of fabric doesn't increase the comfort, six participants mentioned that the fabric does make the stimulus less intense and therefore more comfortable (P3, P5, P6, P7, P8, P11).

- Summary

Despite the complaints from some participants about the intense thermal sensation from high-intensity stimuli, the statistic result shows that thermal stimulus feels neither comfortable nor uncomfortable. Feeling the stimulus through a piece of silk makes no difference compared to experiencing it directly with skin.

Detection time

The Box plot for detection time is shown in Figure 52. Shapiro-Wilk normality tests showed that participants' warm (p$<$0.001) and cool (p$<$0.001) stimuli detection times are both not normally distributed. Therefore, non-parametric statistical tests was conducted.

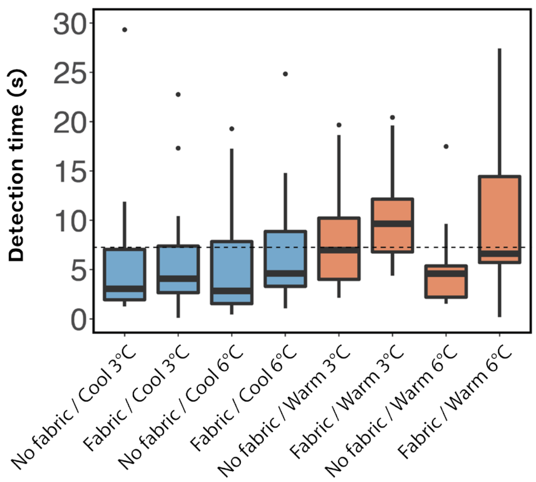


Figure 52. Box plots of detection time for all thermal conditions

- Warm stimulus

Comparing four matched groups within subjects, A Friedman rank sum test is performed directly. A significant effect of thermal intensity and contact medium conditions on warm temperature ratings (c2(3)=32.2), p<0.001) is found. A post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences only between noFabric-6°C and noFabric-3°C (Z = -3.8, p<0.001, r = 0.6), between noFabric-3°C and Fabric 3°C (Z = -2.4, p<0.05, r = 0.4), between noFabric-6°C and Fabric-3°C (Z = -3.6, p<0.001, r = 0.52), and between noFabric-6°C and Fabric-6°C (Z = -3.3, p<0.001, r = 0.5).

- Cold stimulus

Again, by comparing four matched groups within subjects, a Friedman rank sum test is performed. A significant effect of thermal intensity and contact medium conditions on cool stimuli detection times (c2(3)=13.6), p<0.05) is found. A post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences only between noFabric-6°C and Fabric-6°C (Z = -2.2, p<0.05, r = 0.32), and between noFabric-3°C and Fabric-6°C (Z = -2.8, p<0.05, r = 0.41).

- Summary

These results indicate that when participants experience warm stimuli without fabric, there is a large difference between low and high thermal intensity. It takes participants on average 8.00s to detect the low-intensity stimulus. However, the detection time decreases to average 4.70s for higher thermal intensity. For the cold stimuli, there is little difference between low and high thermal intensity. Participants need 5.50s on average to detect lower thermal intensity for cool stimuli. Increasing this intensity shortens detection time only by 0.47s. Adding a piece of silk fabric always delays the perception of thermal stimuli. For warm stimuli, average detection times range from 10.30s (low intensity) to 10.10s (high intensity). For cold stimuli, average detection times range from 6.10s (low intensity) to 7.9s (high intensity). Due to heat transfer between a Peltier element and human skin (Qsp), the ROC differs across contact medium conditions. After several attempts of fine-tuning the PID, we arrived at a rough ROC of 1°C/s. However, with fabric, the ROC was sometimes higher, up to approximately 1.5°C/s. Without the fabric, the ROC was generally lower, to approximately 0.7°C/s. This is likely due to the fabric weakening the heat transfer between upper chest skin and the Peltier element. Since less heat is delivered to or absorbed from the skin within the same time, the Peltier element takes less time to reach the target temperature without any intervention, which explains why detection time increases with the silk fabric on.

Other findings

The hair on the chest might affect the perception of thermal stimulus since it can be regarded as another layer of fabric. Participant 1 and 2, who have hair on their upper chest, mentioned the effect of hair. The temperature of the touching area for the two participants changed quite fast, which behaved similarly to when the silk was added.

When asked about feedback towards the device and the experience, three participants (P4, P10, P12) complained about the Peltier element. They described it as a sticky metal plate without breathing. Two people talked about the positive effect of silk on their acceptance of the device. Participant 5 said that he felt safer with a fabric. Contacting the element with naked skin made him feel like doing an experiment. Participant 7 said that having the silk just made her less worried that she was gonna burn or irritate herself even she knew it wasn't a very strong stimulus.

6.4 Conclusion & thermal choice

Although thermal perception is very different across individuals, people, in general, can feel different intensities for both cold and warm stimulus when it's added on naked skin. Higher intensity feels more intense but doesn't necessarily lead to a less comfortable feeling. Adding a piece of silk weakens the subjective intensity of the stimulus, prolong the detecting time but doesn't increase the subjective comfort very much.

The result of the experiment helps to decide the thermal stimuli used for the second study. Since the stimuli should be detectable for most people within an acceptable range, the low intensities are out of options. For the warm stimulus, high intensity (38C) is used for the second experiment. For the cold one, the intensity is decreased from minus six (26C) to minus four (28C) considering the complaints of discomfort from some participants.

For the contact medium, the fabric is not chosen. For the second experiment, people will experience the thermal stimulus in the context of conversation. Since the voice goes very fast, the thermal stimulus should be perceived quickly as well. Therefore, when appraising the stimuli to interpret emotion, people are more likely to relate the two clues together. Considering that the silk prolongs the detecting time a lot without increasing the comfort, the thermal stimulus will be added on people's skin directly.

EXPERIMENT TWO

/ Chapter 7

Introduction

The purpose of this study is to explore how thermal stimulus on the upper chest can affect emotion perception from neutrally spoken voice messages. Eight normal voice messages were played in a neutral tone to simulate the context that people speak without emotional expression. Each of the voice messages was played in pair with three thermal conditions (warm, cold, baseline) during the experiment. By comparing the ratings of valence and arousal between the ones with and without thermal stimulus, how can the thermal stimulus affect emotion perception from neutrally spoken voice messages is answered.

7.1 Voice stimulus

Before the main part of the second experiment, a set of voice messages was generated and validated with seven people.

Generating

The voice stimuli are from the EU emotion stimulus database [36], in which each stimulus is described in terms of the emotion expressed, the emotional intensity, the valence, and arousal on 5-point scales. Voice stimuli were selected from the database with the following considerations: 1) Since the second experiment is to explore the emotion perception from neutrally spoken emotional messages, the contents of the messages should somehow reveal the valence. Thus, even spoken in a neutral tone, people can still indicate if the speaker is pleasant or not about what he or she says. 2) Another consideration is to keep the speakers' genders balanced as much as possible and therefore to get rid of the effect brought by gender difference. Considering the criteria, the scope was narrowed down to 12 voice messages (six positive and six negative). Table 3 presents the information of these voice messages. To generate the neutrally spoken voice messages for the experiment, Google Text to Speech [37], an AI voice generator with prosody information is applied. All the messages generated are between 1s to 3s.

Voice stimulus	Positive or negative	Script	Emotion	Valence	Arousal
1	Positive	*It's going to be great.*	Excited	4.22	3.48
2		*It's wonderful to see you.*	Happy	3.96	3.63
3		*Hmm, I love chocolate.*	Happy	4.3	3.45
4		*You've done really well.*	Proud	4.05	3.40
5		*I knew I could do it.*	Proud	4.55	3.50
6		*I'm going to bake a pirate cake for the children.*	Excited	4.32	3.59
7	Negative	*What do you think you are doing?*	Angry	1.55	3.68
8		*Ugh...cover your mouth when you sneeze.*	Disgusted	1.71	4.08
9		*I've lost everything.*	Sad	2.65	3.90
10		*I tried so hard.*	Disappointed	2.52	3.57
11		*That wasn't very nice of me.*	Ashamed	2.00	3.24
12		*Look what you've done?*	Angry	2.10	3.43

Table 3. Information of the 12 voice stimuli from EU voice database

Validating

To validate that the neutrally spoken messages are really perceived more neutral than the normally spoken ones, the 12 messages were rated by seven participants through an online questionnaire (Figure 53). Participants listened to a voice message and gave their ratings in terms of valence and arousal on Self-Assessment Manikin (SAM) technique [38], a non-verbal pictorial assessment technique. The sequence of the messages was randomized in advance. The purpose is to see if the neutral tone brings the perceived valence and arousal closer to neutral as expected. Their ratings were collected on 9-point likert scales first and then converted back to five points for comparison. Table 4 shows the comparison between the generated messages and the original ones.

Voice stimulus	Positive or negative	Script	Emotion	Valence_avg	Valence_EU voice	Arousal_avg	Arousal_EU voice
1	Positive	*It's going to be great.*	Excited	3.5	4.2	2.3	3.5
2		*It's wonderful to see you.*	Happy	3.9	3.9	3.6	3.6
3		*Hmm, I love chocolate.*	Happy	3.2	4.3	2.6	3.5
4		*You've done really well.*	Proud	3.7	4.1	3.1	3.4
5		*I knew I could do it.*	Proud	2.9	4.6	3.0	3.5
6		*I'm going to bake a pirate cake for the children.*	Excited	3.9	4.3	3.7	3.6
	Mean			**3.5**	**4.2**	**3.1**	**3.5**
	Median			**3.6**	**4.3**	**3.0**	**3.5**
7	Negative	*What do you think you are doing?*	Angry	1.9	1.6	3.6	3.7
8		*Ugh...cover your mouth when you sneeze.*	Disgusted	1.9	1.7	3.6	4.1
9		*I've lost everything.*	Sad	2.0	2.7	1.6	3.9
10		*I tried so hard.*	Disappointed	2.2	2.5	2.6	3.6
11		*That wasn't very nice of me.*	Ashamed	2.4	2.0	2.1	3.2
12		*Look what you've done?*	Angry	1.9	2.1	3.1	3.4
	Mean			**2.0**	**2.1**	**2.8**	**3.7**
	Median			**2.0**	**2.1**	**2.9**	**3.6**

Table 4. The comparison between the generated voice stimuli and the original voice stimulus from the EU voice database

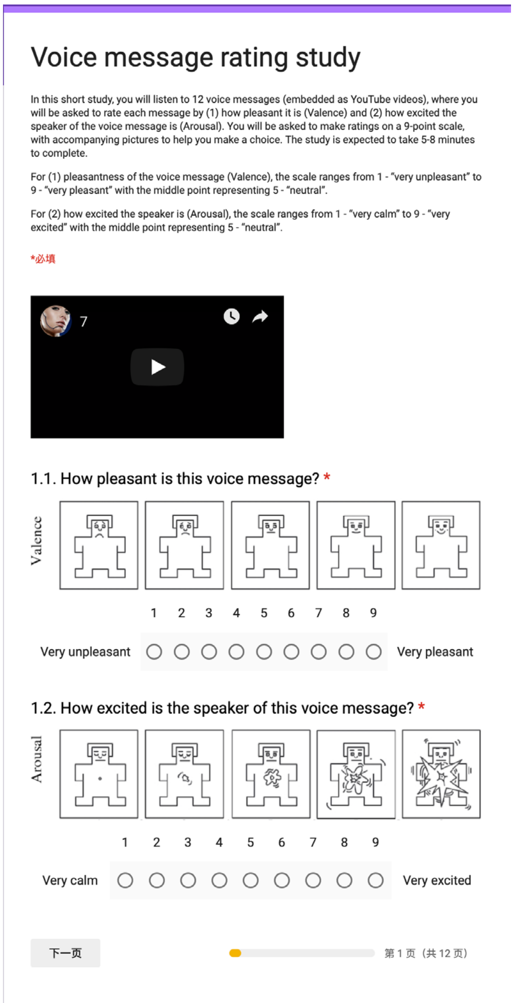


Figure 53. Online questionnaire to collect the ratings on the generated voice message

From the result, the generated messages are perceived as more neutral compared to the normally spoken ones. For valence, the mean value of the positive messages decreased from 4.23 to 3.54 while the negative ones are not affected much. The mean value changed from 2.09 to 2.06. In terms of arousal, the neutral tone decreased the mean value for both positive and negative messages. For the positive messages, the value decreased from 3.51 to 3.06. For the negative ones, the mean value decreased from 3.65 to 2.76.

Although the overall valence and arousal are affected, the selection of message is based on the ratings per message. To select eight messages (four positive, four negative) used for experiment two, I try to involve the ones whose valence and arousal are both affected. According to the results, there are three qualified ones for both positive and negative messages. For the positive message, they are 1, 3 and 4. For the negative ones, they are 7, 8 and 11. However, to get enough messages for the experiment, I also involved 5 and 10 as stimuli although their valence is not affected as expected. (For 5, the valence is changed from 4.55 to 2.93, which means the neutral expression makes people hard to detect if it is a positive or negative message. For 10, the valence decreases instead of increasing.) The eight voice messages used for experiment two are shown in Table 5.

Voice stimulus	Positive or negative	Script	Emotion	Valence	Arousal
1	Positive	*It's going to be great.*	Excited	4.22	3.48
2		*Hmm, I love chocolate.*	Happy	4.3	3.45
3		*You've done really well.*	Proud	4.05	3.40
4		*I knew I could do it.*	Proud	4.55	3.50
5	Negative	*What do you think you are doing?*	Angry	1.55	3.68
6		*Ugh...cover your mouth when you sneeze.*	Disgusted	1.71	4.08
7		*I tried so hard.*	Disappointed	2.52	3.57
8		*That wasn't very nice of me.*	Ashamed	2.00	3.24

Table 5. The eight voice messages selected for the second experiment

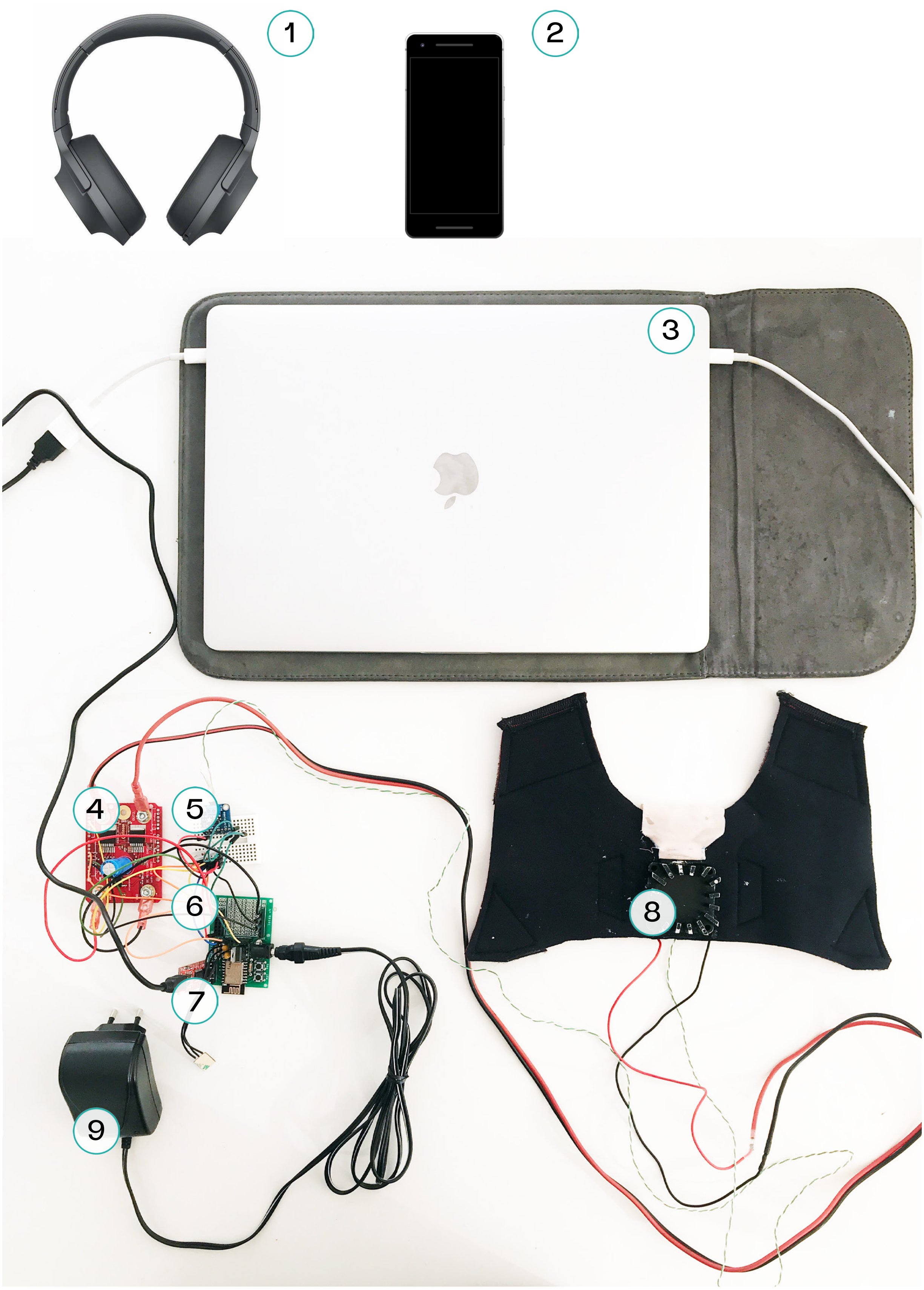
7.2 Updating prototype

Considering that the thermal stimulus should be at the same pace with voice messages in the second experiment. The prototype is updated. Two parts are changed: 1) The control circuit is updated to enable a higher ROC. 2) The application is adjusted to fit the process of the second experiment.

Updating the control circuit

In the first experiment, it takes around six seconds to reach the high-intensity temperature. However, the voice messages used for the second experiment are on average less than two seconds, which is much shorter than the duration of the thermal stimulus. To better fit the context of conversation, a higher ROC is needed. To achieve that, PID control is abandoned when the element goes to a setpoint. Instead, the constant maximum output value is applied to drive the element until it reaches the target temperature. Besides, the motor driver used for experiment one can only output 5.5V as the maximum even if a 9V power supply is applied as input. After talking to an expert, it's because the module of this motor driver is too old and the rest energy is lost on the driver itself. Since the higher output value means higher current and leads to a higher ROC, the driver is changed into a more efficient one. To avoid the increased heat generated due to resistance brought by the higher current, we decrease the voltage applied to 7.5V.

Another thing I did is to add a buffer range for the output value. It's because the high current without slowing down always push the temperature over the setpoint. Therefore, setting a range for lower output value before the temperature reaches the target is necessary. After several attempts, I found that the temperature seldom went below Setpoint when the element was cooling. Therefore, I set different buffer ranges for heating and cooling. For heating, there are two buffer ranges. Between 35°C to 37.75°C, the output value is 300. When the temperature is between 37.75°C to 38°C, the output value is zero. As for cooling, the output value is zero when the temperature is between 28.25°C to 28°C. Between 28.75°C to 28.25°C, the output value is -900. After testing it on myself and another person, the voltage works fine if there are two breaks during the experiment to cool Peltier element down.



1 - Headphone

2 - Smart phone

3 - Laptop

4 - Motor driver

5 - Thermocouple

6 - Iotsa board

7 - USB to TTL serial adapter

8 - Peltier element with heat sink

9 - 7.5V power supply

Figure 54. The devices used for the second experiment

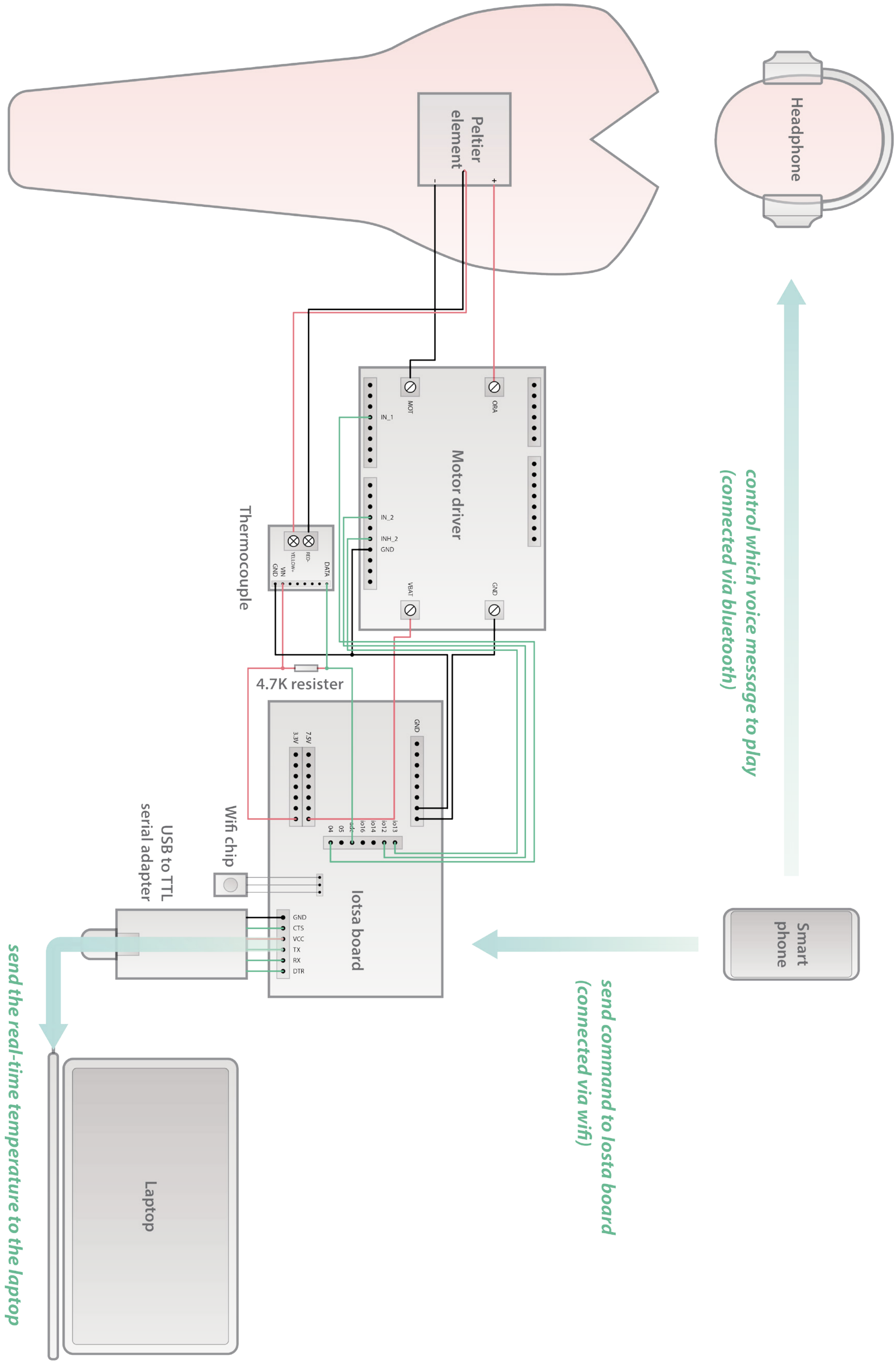


Figure 55. The illustration of the system

Updating Android application

The application is also adjusted according to the requirement of the second experiment. The application sends commands to the board to generate a four-second thermal stimulus and plays a voice message at the same time. The sequence of the stimulus is randomized and counterbalanced. After each stimulus, participants' ratings on valence and arousal of the voice messages are collected by the application and saved for later analysis. Figure 56 shows the process of the application.

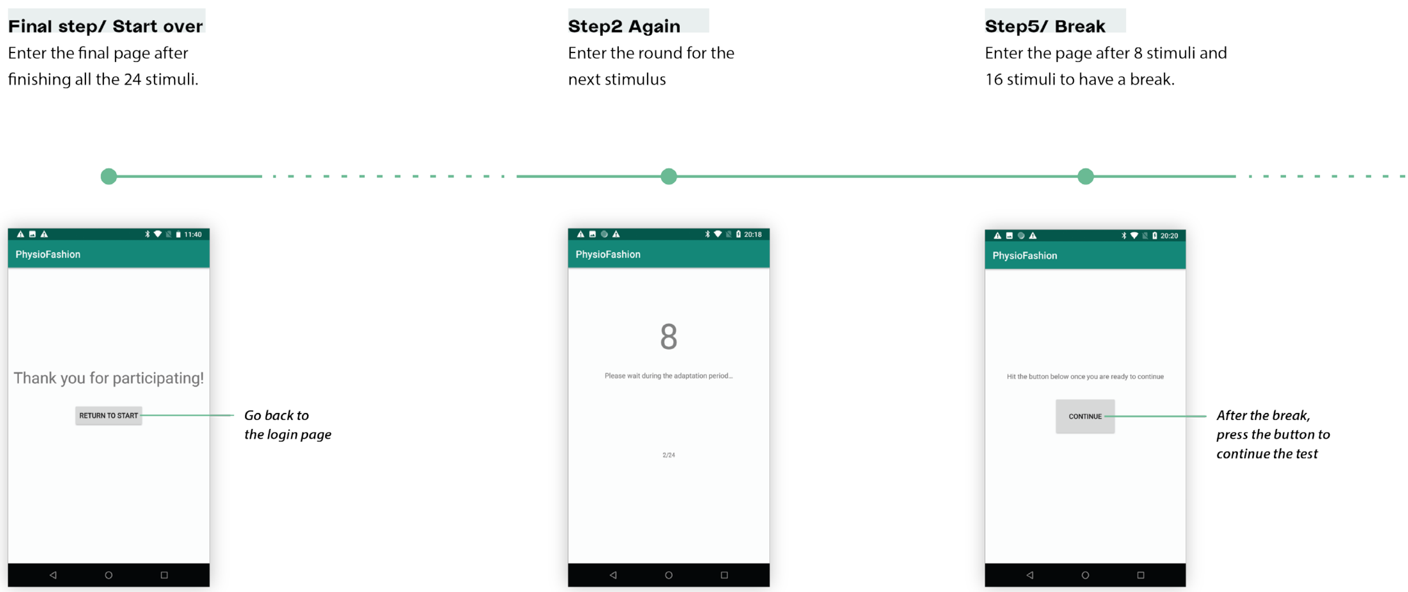


Figure 56. The workflow of the application - Version for experiment two

Step1/ Basic info.

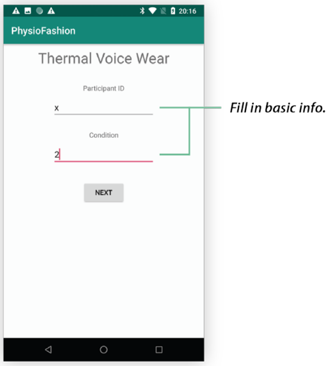
Input participant ID, the number of the first thermal condition and if the fabric is on or off.

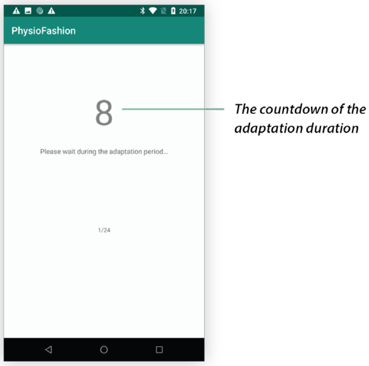
Step2/ Adaptation

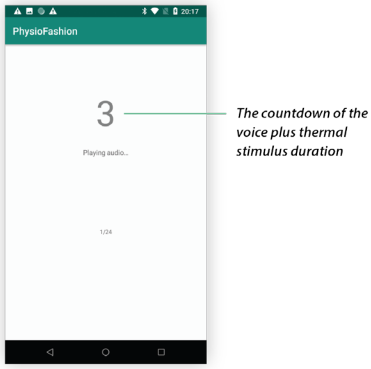
Adapt your skin temperature to the baseline temperature of 32°C. The adaptation lasts for 10 seconds.

Step3/ Experiencing stimuli (voice plus thermal)

The stimulus is added for 4 seconds.





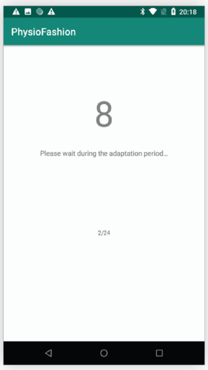


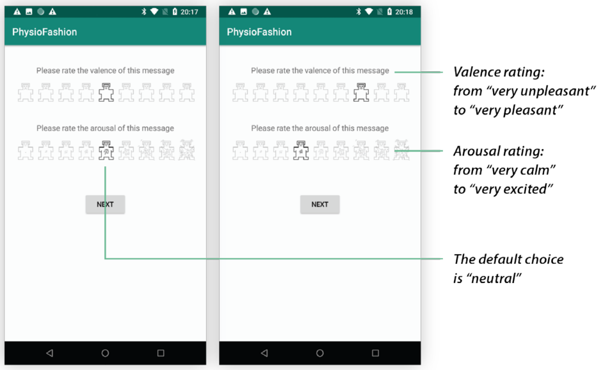
Step2 Again

Enter the round for the next stimulus

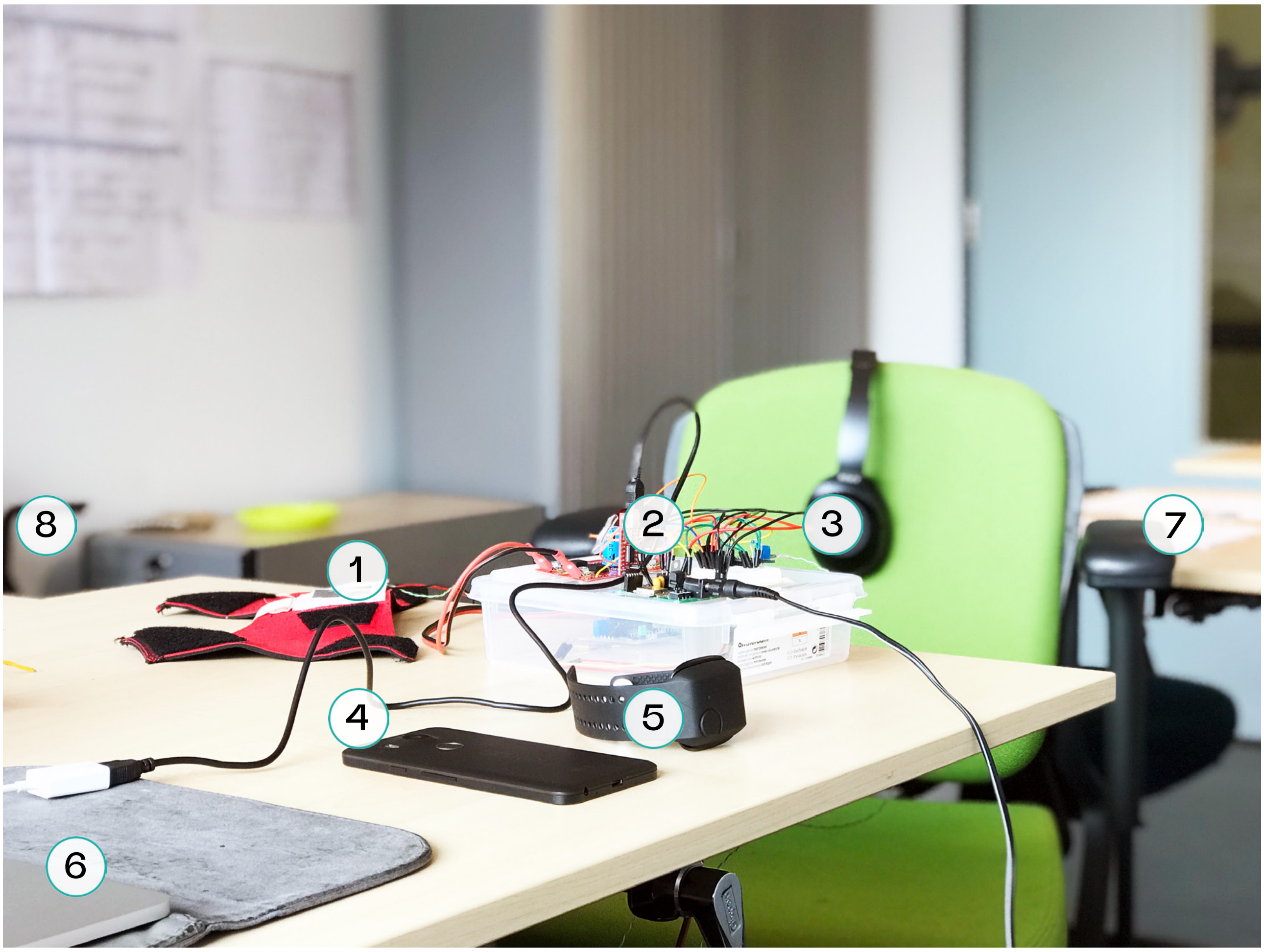
Step4/ Ratings

Input the ratings in terms of valence and arousal of the voice message.





7.3 Setup



1 - **Peltier element**	2 - **Iotsa board**	3 - **Headphone**	4 - **Smart phone**
5 - **E4 wrist band**	6 - **Laptop**	7 - **Paper forms & voucher**	8 - **Shirt for experiment**

Figure 57. Experiment setup

As study one, the experiment was conducted in a room of 23°C. The control circuit, the application, and the laptop were connected through wifi (Figure 57). A headphone connected to the Android phone was offered to play the voice messages. The Paper forms were offered. The real-time temperature of the touching side of the Peltier element was monitored through a window on the laptop. A thermometer was used to measure the room temperature and an E4 wristband was used to collect the skin temperature. 12 participants (six males, six females) were invited for the experiment. They are researchers from CWI and master students from TU Delft.

7.4 Process

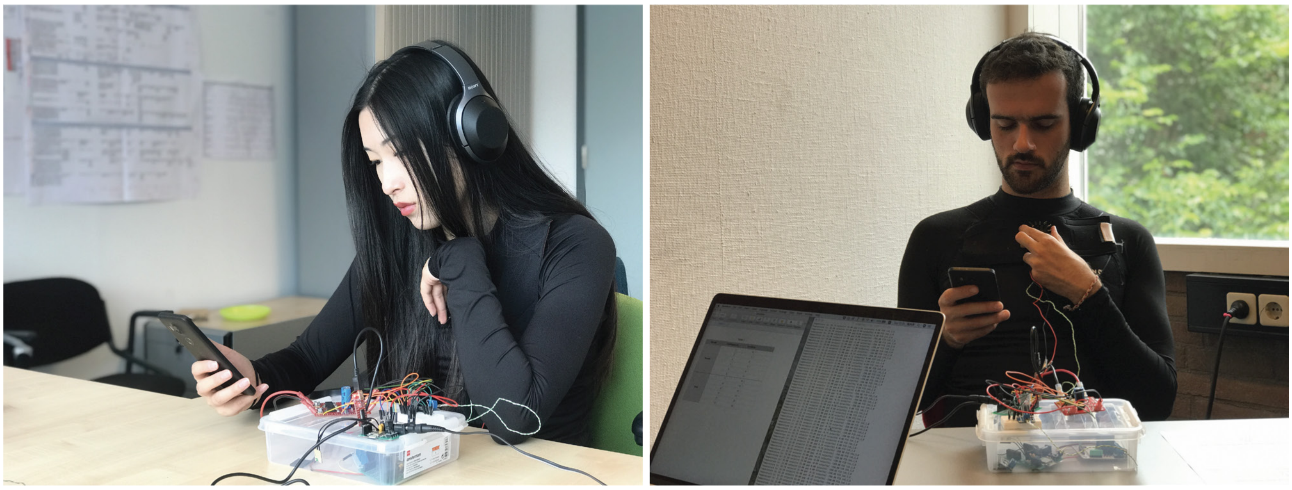


Figure 58. Prticipants performing tasks in experiment two

The process of the introduction phase is the same as the first experiment. Afterward, they put on the clothes with Peltier element on the upper chest and receive a calibration session. During the session, they got familiar with the stimuli and application by experiencing a cold and warm stimulus paired with voice messages (Figure 58).

For the main tasks of the experiment, participants experienced 24 trials (four positive messages, four negative messages, each paired with three thermal conditions including warm, cold and baseline). There were two-minute breaks after trial eight and sixteen to cool the Peltier element down. The sequence of the stimulus was randomized. The first condition was counterbalanced across participants. Before every stimulus, there was a ten-second duration to adapt to the temperature of the touching area to the baseline of 32°C. In the period of the four-second stimulus, the participant would listen to a voice message accompanied with a thermal stimulus which last for four seconds. After experiencing each stimulus, the participant gave feedback in terms of valence and arousal on the 9-point likert scales on the phone application. Throughout the process, they were encouraged to think aloud about their feelings in terms of thermal sensation and the emotion perceived from the voice. Figure 59 illustrates the process of the main tasks. After going through all the trials, a short semi-structured interview was conducted. They were asked to recall the stimuli experienced and talk about the differences they felt between different conditions. They were also encouraged to give open feedback. The whole process was recorded by an audio recorder. After the interview was over, they were rewarded with a 10 euro voucher. The whole process took around 45 minutes.

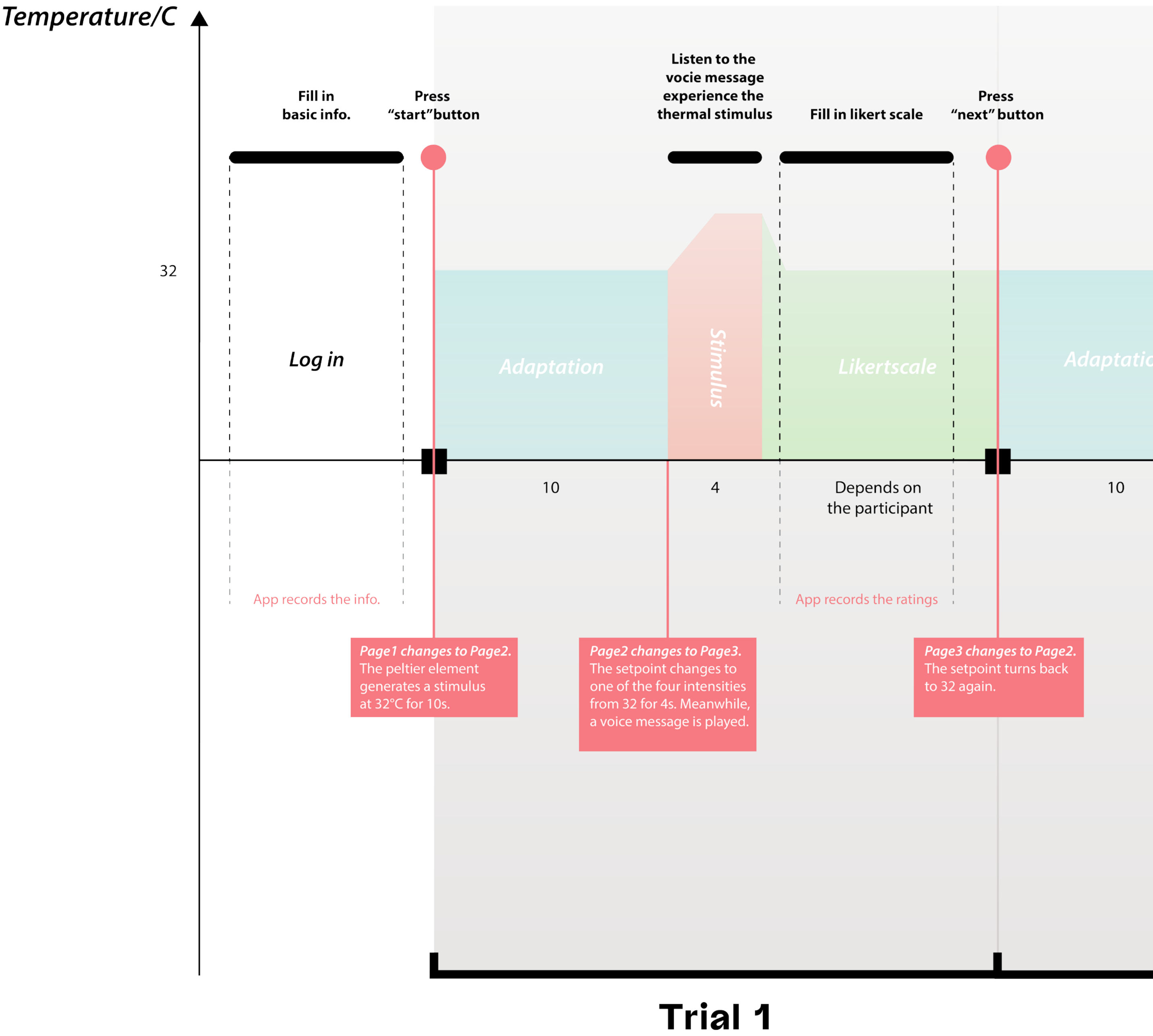
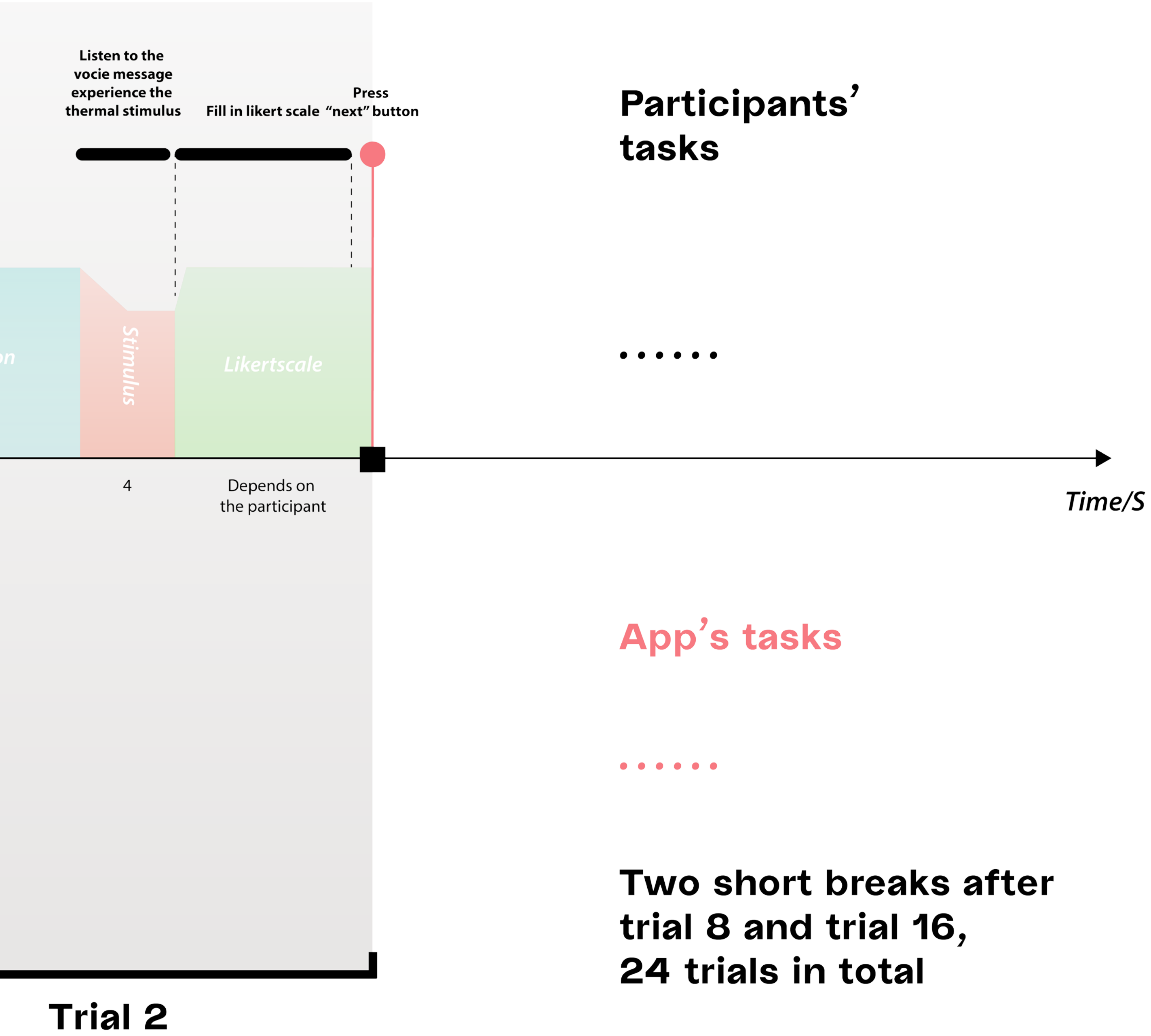


Figure 59. Process of the main task



Participants’ tasks

• • • • • •

App’s tasks

• • • • • •

Two short breaks after trial 8 and trial 16, 24 trials in total

7.5 Result analysis

The results collected from 12 participants were analyzed in RStudio. From the result, both valence and arousal can be affected by the thermal stimulus. Different directions of increase/decrease in valence depend on warming/cooling.

Warming increases the valence of positive messages with no effect on negative ones. Cooling doesn't have much effect on positive messages but brings down the valence of negative messages. Thermal stimulation generally increases arousal, though not uniformly across positive and negative messages. Cooling increases arousal for negative messages, while warming increases arousal for positive messages and increases the arousal for negative stimuli slightly.

The following parts present the statistic results and the summarised qualitative feedback from participants. Box plots for valence and arousal ratings across thermal stimuli and message valence factors are shown in Figure 60 and Figure 61 respectively. Upper and lower dashed lines show the mean for positive and negative messages, respectively. Shapiro-Wilk normality tests showed that participants' valence ratings for positive ($p<0.001$) and negative ($p<0.05$) messages and arousal ratings for positive ($p<0.05$) and negative ($p<0.05$) messages are not normally distributed, and thereafter non-parametric statistical tests were conducted. The complete qualitative feedback with the profile information of each participant can be found in Appendix.

Valence

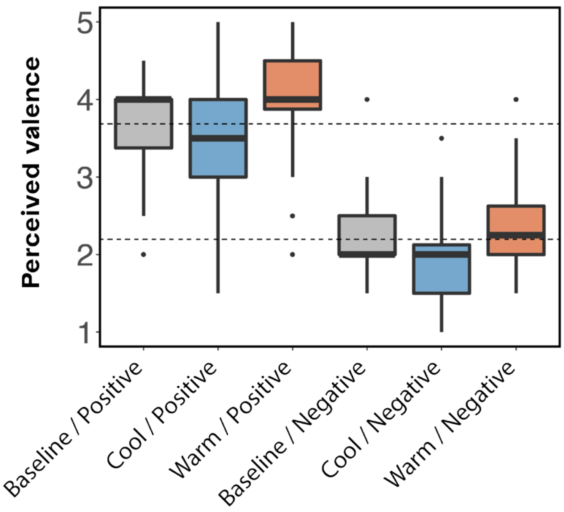


Figure 60. Box plots of valence ratings

- Positive voice messages

Comparing three matched groups within subjects, a Friedman rank sum test was performed. A significant effect of thermal stimuli on valence ratings (c2(2)=19.0), $p<0.001$) was found. A posthoc test using Mann-Whitney tests with Bonferroni correction showed significant differences between baseline and warm ($Z = 2.4$, $p<0.05$, $r = 0.4$), baseline and cool ($Z = -2.8$, $p<0.05$, $r = 0.3$), and warm and cool ($Z = 3.8$, $p<0.001$, $r = 0.4$).

- Negative voice messages

Comparing three matched groups within subjects, a Friedman rank sum test was performed. A significant effect of thermal stimuli on valence ratings (c2(2)=11.7), $p<0.05$) was found. A post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences only between baseline and cool ($Z = 3.5$, $p<0.05$, $r = 0.4$), and warm and cool ($Z = 2.9$, $p<0.05$, $r = 0.3$).

Arousal

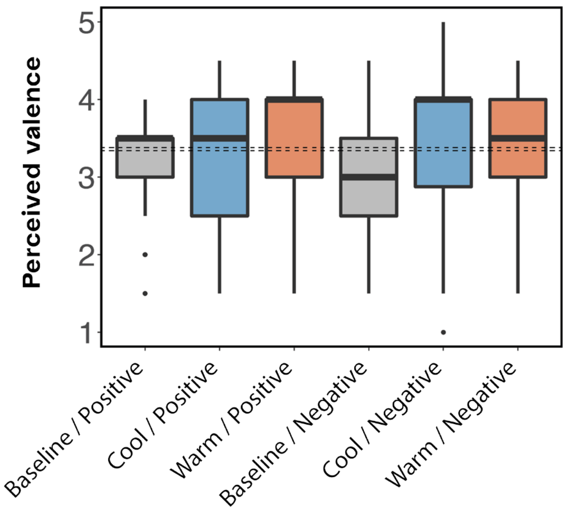


Figure 61. Box plots of valence ratings

- Positive voice messages

Comparing three matched groups within subjects, a Friedman rank sum test was performed. A significant effect of thermal stimuli on valence ratings (c2(2)=11.3), $p<0.05$) was found. A post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences only between baseline and warm ($Z = 3.1$, $p<0.05$, $r = 0.5$), and warm and cool ($Z = 2.2$, $p<0.05$, $r = 0.3$).

- Negative voice messages

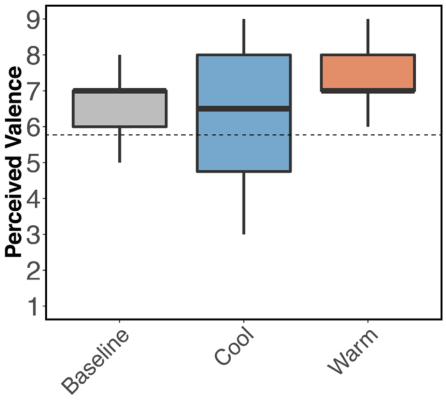
Comparing three matched groups within subjects, a Friedman rank sum test was performed. A significant effect of thermal stimuli on valence ratings (c2(2)=13.4), $p<0.05$) was found. A post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences only between baseline and warm ($Z = 3.2$, $p<0.001$, $r = 0.5$), and baseline and cool ($Z = 2.9$, $p<0.05$, $r = 0.4$).

Analysis per sentence

Although the statistic results show the general patterns of emotion perception from neutrally spoken voice messages to some degree, there are some disagreements on some aspects. (e.g., the arousal results of cold stimulus has a wide range of distribution, which represents the participants' disagreement on the ratings.) Even for the ones already showing patterns, more factors need to be looked into to interpret the results thoroughly. Differences among the four messages and across individuals might contribute to the distribution of the ratings. Looking into the factors helps to make a better sense of the results. To further explain the results by taking the differences across scripts into consideration, the plots per sentence is generated. The overview of the plots and rating changes in terms of valence and arousal for all the voice messages across 12 participants are shown in Figure 62 and Figure 63. The detailed interpretation per sentence is described in Appendix.

Positive messages

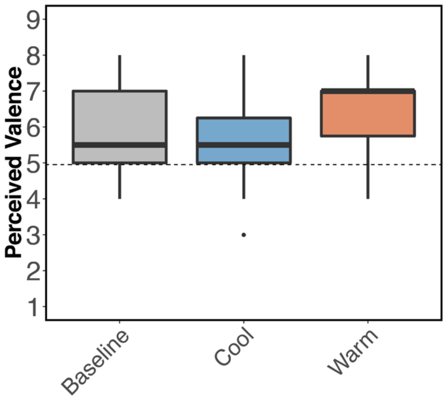
It's going to be great.



Positive Message 1_valence

Compared to baseline	Warm	Cool
Increase	*7 participants* P1, P2, P5, P8, P9, P10, P11	*4* P1, P5, P10, P11
Decrease	*1* P3	*7* P2, P3, P4, P7, P8, P9, P12
No change	*4* P4, P6, P7, P12	*1* P6

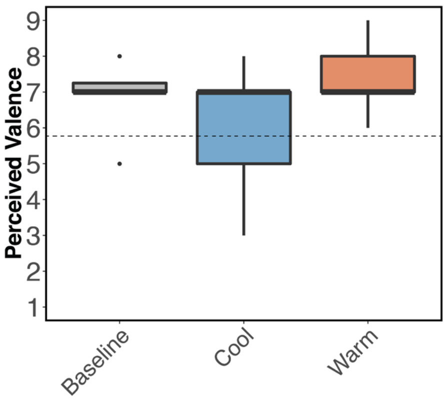
Hmm, I love chocolate.



Positive Message 2_valence

Compared to baseline	Warm	Cool
Increase	*4 participants* P6, P7, P8, P9	*4* P7, P8, P9, P10
Decrease	*2* P10, P11	*2* P1, P3
No change	*6* P1, P2, P3, P4, P5	*6* P2, P4, P5, P6, P11, P12

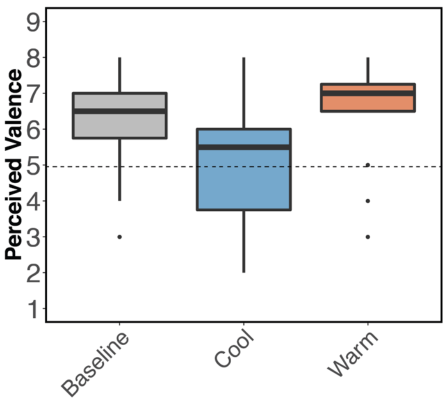
You've done really well.



Positive Message 3_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P1, P2, P3, P7, P8	*1* P4
Decrease	*3* P5, P6,P10	*6* P2, P5, P7, P8, P11, P12
No change	*4* P4, P9, P11, P12	*5* P1, P3, P6, P9, P10

I knew I could do it.



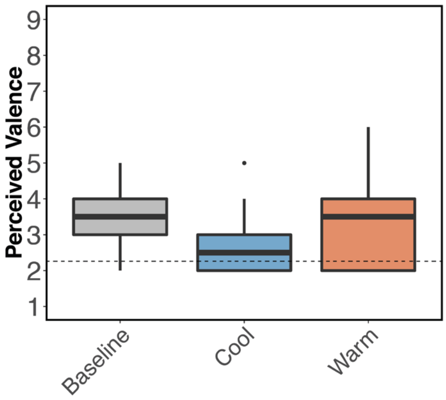
Positive Message 4_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P1, P3, P5, P8, P12	*2* P4, P10
Decrease	*1* P10	*9* P1, P2, P3, P5, P6, P7, P8, P9, P12
No change	*6* P2, P4, P6, P7, P9, P11	*1* P11

Figure 62. Valence feedback per message

Negative messages

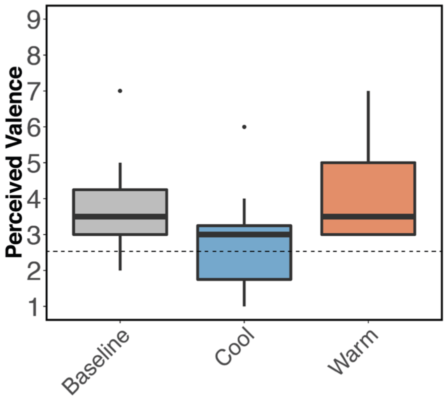
What do you think you are doing?



Negative Message 1_valence

Compared to baseline	Warm	Cool
Increase	*3 participants* P1, P6, P8	*0*
Decrease	*3* P3, P5, P11	*8* P1, P2, P3, P4, P5, P7, P8, P11
No change	*6* P2, P4, P7, P9, P10, P12	*4* P6, P9, P10, P12

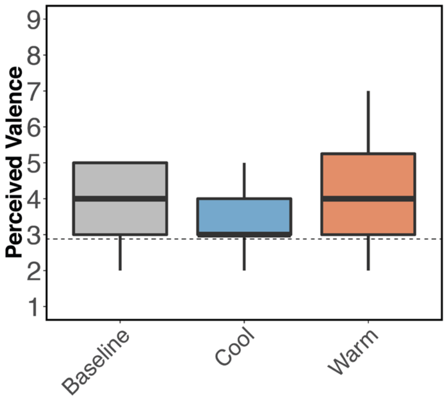
Ugh...Cover your mouth when you sneeze.



Negative Message 2_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P2, P3, P9, P11, P12	*2* P9, P11
Decrease	*2* P5, P7	*7* P1, P2, P3, P5, P7, P8, P10
No change	*5* P1, P4, P6, P8, P10	*3* P4, P6, P12

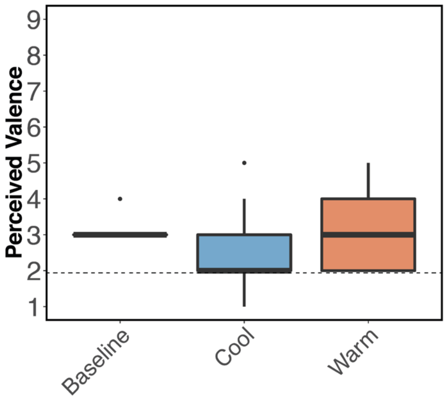
I tried so hard.



Negative Message 3_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P1, P2, P5, P7, P9	*1* P5
Decrease	*4* P6, P10, P11, P12	*6* P1, P2, P6, P8, P10, P12
No change	*3* P3, P4, P8	*5* P3, P4, P7, P9, P11

That wasn't very nice of me.

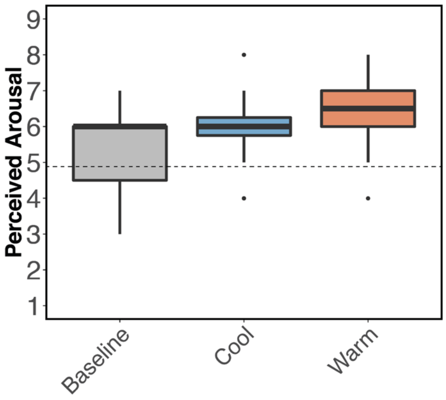


Negative Message 4_valence

Compared to baseline	Warm	Cool
Increase	*4 participants* P2, P6, P8, P12	*2* P5, P10
Decrease	*5* P3, P4, P7, P9, P11	*9* P1, P2, P3, P4, P7, P8, P9, P11, P12
No change	*3* P1, P5, P10	*1* P6

Positive messages

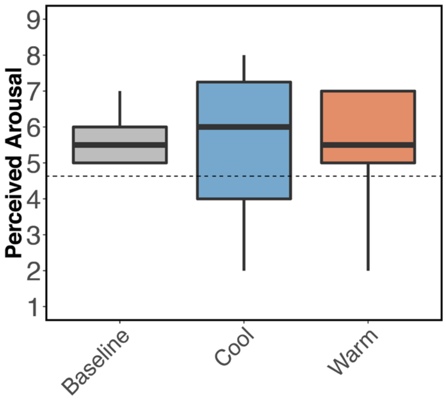
It's going to be great.



Positive Message 1_arousal

Compared to baseline	Warm	Cool
Increase	*8 participants* P1, P2, P3, P7, P10, P11, P8, P9	*5* P3, P5, P7, P11, P9
Decrease	*3* P4, P6, P12	*4* P1, P2, P4, P6,
No change	*1* P5,	*3* P10, P12, P8

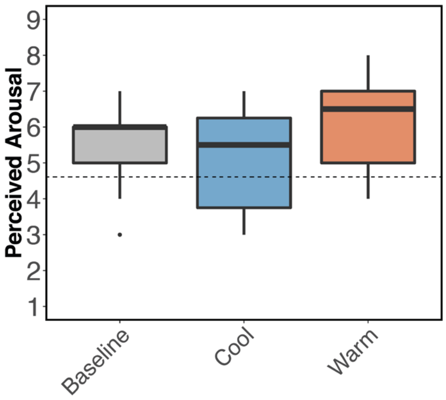
Hmm, I love chocolate.



Positive Message 2_arousal

Compared to baseline	Warm	Cool
Increase	*5 participants* P5, P7, P8, P9, P10	*7* P5, P6, P7, P8, P9, P10, P11
Decrease	*3* P3, P11, P12,	*4* P1, P2, P3, P12,
No change	*4* P1, P2, P4, P6	*1* P4,

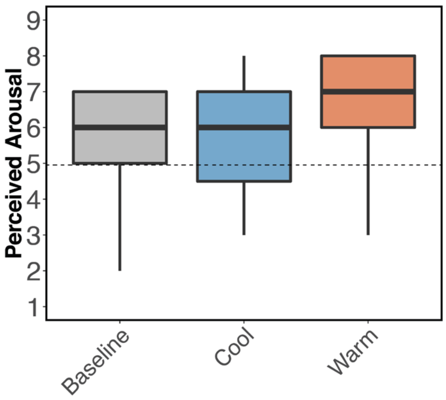
You've done really well.



Positive Message 3_arousal

Compared to baseline	Warm	Cool
Increase	*7 participants* P1, P2, P5, P7, P8, P9, P10	*3* P2, P5, P9
Decrease	*2* P4, P6	*6* P1, P3, P6, P7, P10, P11
No change	*3* P3, P11, P12	*3* P4, P8, P12

I knew I could do it.



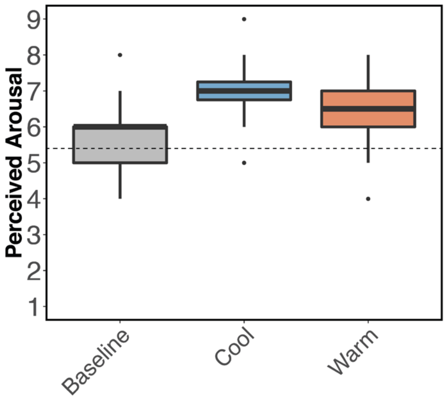
Positive Message 4_arousal

Compared to baseline	Warm	Cool
Increase	*6 participants* P5, P6, P8, P9, P10, P11,	*5* P5, P8, P10, P11, P3,
Decrease	*2* P12, P3,	*3* P1, P12, P7,
No change	*4* P1, P2, P4, P7,	*4* P2, P4, P6, P9

Figure 63. Arousal feedback per message

Negative messages

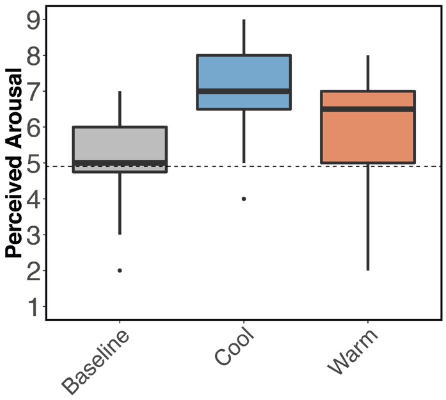
What do you think you are doing?



Negative Message 1_arousal

Compared to baseline	Warm	Cool
Increase	*6 participants* P1, P3, P5, P6, P7, P10,	*10* P1, P2, P3, P4, P5, P7, P8, P9, P10, P11,
Decrease	*4* P2, P4, P9, P11,	*0*
No change	*2* P8, P12,	*2* P6, P12,

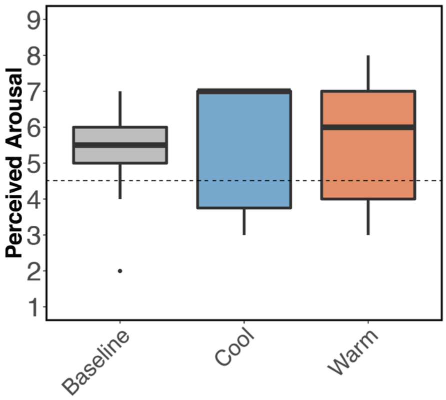
Ugh....Cover your mouth when you sneeze.



Negative Message 2_arousal

Compared to baseline	Warm	Cool
Increase	*7 participants* P1, P3, P5, P7, P8, P9, P12	*10* P1, P2, P3, P4, P5, P7, P8, P10, P11, P12,
Decrease	*3* P2, P10, P11,	*1* P9
No change	*2* P4, P6	*1* P6,

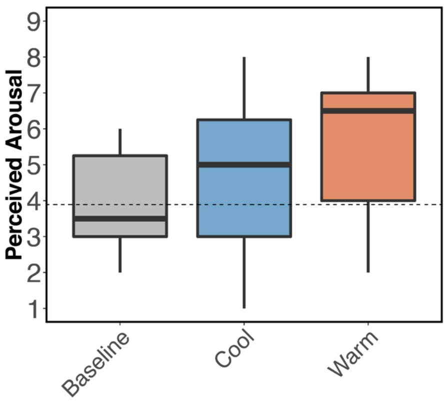
I tried so hard.



Negative Message 3_arousal

Compared to baseline	Warm	Cool
Increase	*6 participants* P1, P2, P5, P7, P9, P11	*7* P2, P3, P5, P7, P8, P9, P10
Decrease	*3* P3, P10, P12,	*2* P11, P12,
No change	*3* P4, P6, P8,	*3* P1, P4, P6,

That wasn't very nice of me.



Negative Message 4_arousal

Compared to baseline	Warm	Cool
Increase	*10 participants* P1, P2, P4, P5, P6, P7, P8, P10, P11, P12	*6* P2, P4, P7, P8, P11, P12,
Decrease	*0*	*4* P3, P6, P9, P10
No change	*2* P3, P9	*2* P1, P5,

Looking into the ratings per sentence on an individual level adds more details and brings corrections to the general findings.

Almost for all conditions, there is no complete agreement on how thermal stimulus changes emotion perception (increase or decrease on valence and arousal) from voice messages. Considering that thermal perception and emotion perception are both subjective processes, the differences in the ratings are quite understandable. In spite of the minority with different feelings, some trends do exist even across different messages, which is in line with the statistic results from the whole messages. For the parts where no patterns are found (e.g., cold stimulus' effect on arousal for negative messages.), there exist neither consistent ratings within the same sentence across individuals nor similar patterns across different sentences.

- Valence

From the plots, valence from positive messages is increased by the warm stimulus. However, the proportion of people feeling that there is no change is similar to the ones feeling the increasing effects. Therefore, the heat tends to increase valence if the person is affected by the stimulus. For the negative messages, the proportions of people giving higher and lower ratings are different between sentences. For example, the majority for message one chooses no change while it's of the lowest proportion for message three and four, which leads to an unclear overall trend. The decreasing effect on valence by the cold stimulus is quite consistent across the four negative sentences. For the positive sentences, the decreasing effect is not obvious because the consistent decreasing only applies to message three and four.

- Arousal

For arousal, the warm stimulus has an increasing effect on both positive and negative messages. Just for the positive messages, the increasing effect is stronger. What worth mentioning is that the ratings on negative message four (That wasn't very nice of me.) are very consistent. Ten participants think that the heat increases arousal while two persons feel no change. The plots show that cold stimulus increases arousal for negative messages. While the ratings from per sentence agree with the statement, four participants, which represents a relatively high proportion, feel that the fourth message decreases arousal. For positive messages, there are no agreed ratings either within the same sentence across individuals or among different sentences.

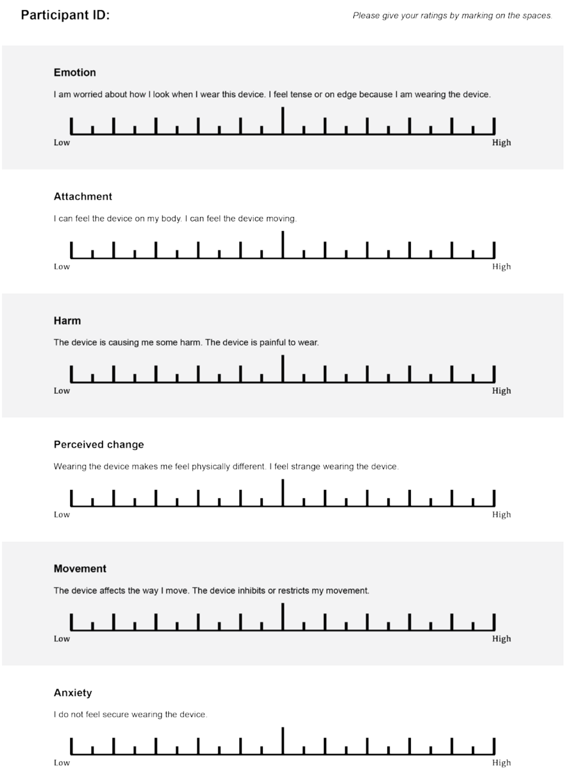
Other findings

Apart from the quantitative results, the qualitative data collected from the semi-structured interview and the thinking aloud is summarised.

First, three participants (P4, P5, P11) said that it is the rate of change that dominates the arousal, not the temperature itself. Two people (P1, P5) mentioned that when the content itself contains no information about valence, they turn to the thermal stimulus for valence detection since it becomes the only clue. Participant two and eight said that they tend to figure out the intention of the message when it's combined with thermal stimulus. Participants eleven said that the current stimulus is a little bit localized. He got the idea that people do experience heat change inside the body when they feel emotions. He pointed out that the stimulus was limited to a point with the current prototype. To simulating the arousal change, a full-body experience with a larger area might have better effects.

Feedback on comfort

Apart from the emotion perception from voice messages, participants' feedbacks on the device's comfort is also collected with Comfort Rating Scales [39] (Figure 64). Since the prototype is of the initial phase with unregulated wires, the feedback is regarded more as a reference for the further development of the device rather than the final evaluation of the product.


Participant ID:

Please give your ratings by marking on the spaces.

Emotion

I am worried about how I look when I wear this device. I feel tense or on edge because I am wearing the device.

Low High

Attachment

I can feel the device on my body. I can feel the device moving.

Low High

Harm

The device is causing me some harm. The device is painful to wear.

Low High

Perceived change

Wearing the device makes me feel physically different. I feel strange wearing the device.

Low High

Movement

The device affects the way I move. The device inhibits or restricts my movement.

Low High

Anxiety

I do not feel secure wearing the device.

Low High

Figure 64. Comfort Rating Scales

On each 20-point scale, the lower the score is, the more it contributes to overall subjective comfort. The results for each factor are as follows: Emotion (Md=13, IQR=12.3), Attachment (Md=10.5, IQR=6.6), Harm (Md=3, IQR=10), Perceived Change (Md=9.5, IQR=9.5), Movement (Md=11, IQR=8.8), Anxiety (Md=8.5, IQR=5.8).

The result reveals two concerns about the device: 1) On a physical level, the negative effect on body movement. For example, participant ten said that the device would affect him a lot when doing sports. Considering the wires and the still bulky heat sink, this is easy to understand. 2) On a mental level, feeling strange of wearing the device. What worth mentioning is that while most people express their concerns about the current look of the device and show a low acceptance. Participant five said that the device made her feel special since she had something others didn't have. She described it like wearing a watch on my wrist while others don't". The device behaves well on "Harm". The prototype doesn't cause any pain to the participants and they are in general not worried about the safety of wearing the device.

7.6 Conclusion

Emotion perception from neutrally spoken voice messages is a complex process related to lots of factors. Adding a thermal stimulus on the upper chest offers an extra clue to interprate the speaker's emotional states, especially when the voice itself contains poor affection information. It seems that individuals have their way of interpreting emotions from voice messages. Besides, the differences between different sentences also contribute to the disagreement on the ratings.

Despite the variables, the universal patterns do exist from the experiment. Warm stimulus increases the perceived valence of positive messages while cold stimulus brings the valence down for the negative ones. For arousal, both warm and cold stimulus can increase that of positive messages but only the cold stimulus has an increasing effect on negative messages. Also, from the verbal feedback, it seems like ROC, compared to EOC, has more effect on the emotion perception.

As for the comfort of the prototype, participants are generally not worried about safety. Their concerns about the movement and social acceptance are the main issues to be addressed to push the prototype into the next level from an application perspective.

These results are the outcome of the exploration of the thermal stimulus. How the results contribute to the research question is discussed in the next chapter.

REFLECTION

/ Chapter 8

8.1 Contribution

Looking back to the research question:

How can wearable thermal display contribute to emotion interpretation from neutrally spoken voice message?

we need to take both the results from the second experiment and the validation of the generated voice messages into account. The neutral tone brings the original EU voice to neutral, which support the problem framed at the beginning of the project. Therefore, the expectation is that the thermal stimulus, as an extra channel, could augment the valence or arousal of these plain voices. The findings of the second experiment do shows the augmenting effect of thermal stimulus.

On a general level, the warm stimulus on the upper chest will augment people's sense of the pleasant feeling of a plain speaker. If it's a negative message, the cold stimulus can be applied to augment the percieved negativeness. Therefore, the augmenting effect is likely to help people better understand the emotional states of the speaker. This would open a new channel for people to interprate others' emotional state, which has the potential to contribute to the efficiency of communication and enhance social connection.

However, augmenting emotion perception doesn't necessarily mean the accuracy of emotion perception. The difficulty here is that there is no standard emotion state in the scenario. The listener and the speaker both have their appraisal of the speaker's emotional state. Besides, when speaking, a person can only choose one way of expression - either neutral or emotional. Therefore, when the speaker is speaking neutrally, we cannot get another emotional version of the same sentence. Given the discussion above, the thermal's augmenting effect on emotion perception can be regarded as a satisfying contribution to the research question.

Apart from thermal's effect on emotion perception, the project studied thermal sensation in the first experiment. The findings are in line with previous research and lead to the proper thermal stimuli applied in the context of verbal communication.

The techniques to build a wearable thermal display augmenting voice messages are also explored. The fabrication methods and the control loop can be transferred to conduct more research about wearable thermal display or precise thermal control.

8.2 Limitation

About the research path

The project studies the emotion perception issue mainly from the perspective of the dimensional model, which might be not sufficient to connect the experiment results to the real-world phenomenon. For example, the warm stimulus tends to increase both valence and arousal of the positive messages. However, from the circumplex model, the emotions from the high arousal quadrant and low arousal quadrant on the high valence side are different. If the warm stimulus affects the two types of emotions differently is not addressed. The voice stimulus from EU voice database is labeled with both emotion identified and valence and arousal. However, when selecting the voice messages from EU voice database, I only focus on the valence and arousal ratings without any consideration about what the emotion is. To get a more thorough study, conducting research based on emotion categories might be a direction.

Besides, when determining the body location for the experiment, the upper chest and forearm are both potential options. I picked the upper chest because of the time limitation. Even with the upper chest, the area difference of the stimulus is not considered. Now it's a point where the Peltier element touches people's skin. If a bigger area might cause a different effect is not addressed, which is also mentioned from one participant in the second experiment.

About experiments

The project aims to explore the effect of the thermal stimulus on emotion perception from plain voices on a fundamental level. To experiment, the problem is abstracted from the complex real-world environment. However, simulating the real-world situation can never reach the ideal state. First, the voices used for the experiment, although have been selected based on a certain consideration and test with participants, can not be representative enough to cover the whole context of daily verbal communication. Besides, the participants perform the tasks while sitting in a room of 23°C. However, listening to others talking through a phone can happen anywhere in the real world. This would bring much more variables like the environment temperature, humidity, wind speed, and background noise.

Another limitation comes from the differences across individuals including the capability of thermal sensation and English proficiency. These factors might affect how people interpret emotion from voice messages.

Apart from the above, the prototype also brings limitations to the study. Although it can achieve the stimulus to a certain extent, both the ROC of thermal stimulus and the contact condition between the Peltier element and the skin can not be controlled very precisely across individuals. This would cause some differences in the thermal conditions across participants.

About the prototype

The current prototype is more like an experiment equipment rather than a device for daily life. Firstly, the device can't work continuously for a long period because of the heat-dissipation problem. Besides, the elements of the prototype like modules or wires are not regulated. Therefore, the electronics and the clothes are not integrated as a whole object. This affects the mobility of the user. It might also cause a low acceptance because of the safety and appearance. Currently the Peltier element touches people's skin by attaching the vest part to the shirt with hooks and loops. Because of the weight of the heat sink. The attachment of the vest part is not tight enough. Sometimes, people need to press the heat sink to clearly feel the thermal stimuli.

8.3 Recommendation

About the research path

To get a further understanding of the research question, future researchers can also proceed the topic from a discrete emotion perspective and study the effect of thermal stimulus according to a specific emotion or a certain type of emotion from the same quadrant of the circumplex model.

According to the feedback from the participants, for the future research, adding the stimulus to different body locations or touching areas can be useful to study a full-body emotional experience. Also, exploring the topic with thermal stimuli of different ROC might be a promising direction.

About experiments

To bring the research closer to the problem existing in the real world, more parameters like the effect of the environment temperature or the background noise need to be studied in further research.

To get rid of the effect from individual differences, it's better to conduct a pre-study to involve participants with similar thermal sensation and English proficiency. (e.g., recruiting native English speakers without hair on the upper chest.)

About the prototype

As for the prototype, to tackle the heat - dissipation issue without bringing more interruptions on emotion perception, water cooling can be a direction to explore in the future. To integrate the electronics with the fabric, conductive fiber can be used to connect different parts of the control circuit on the clothes. For the current version of the prototype, the vest part is attached to the shirt with hooks and loops so that it can be removed and transferred between the female shirt and male shirt easily. This is because of the consideration of experimenting easily and the limitation of time. To achieve a tighter contact between the element and skin, the vest part should be sewed on the upper chest of the shirt.

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Appendix 1

Sensitizing booklet

Introduction

This booklet is used to get you in the mood of the topic. I'm interested in your perspective. Your inputs are valuable for my research.

There are no wrong answers to the questions in this booklets. Your inputs are confidential and will only be used within this study. Your real name will not be used during the rest of this research. Feel free to include drawings or any other means as you want.

Best wishes,
Xingyu

Remote communications in close relationships

* Pictures showing remote communications between friends, family, relatives and partners

Day 1

My top two most memorable moments:
about getting others' emotional states during remote communications (with friends, family or relatives, partners...)

1. Feel free to write down any experience as long as you have a reason why it's memorable. ....

e.g., misunderstand others' emotions, sense others' emotions strongly ....

....

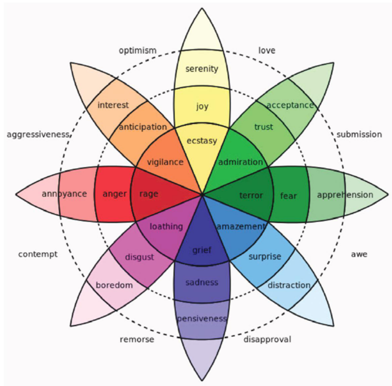
2. ....

....

....

My experience

During the 5 days, please pick and record two moments
about interpreting others' emotional states during a remote comunication
(e.g., feel the other's emotional state clearly or ambiguously; just feel the moment is impressive and worth noting)



* The emotion wheel on the right just serve as a reminder and inspiration. You can write down whatever word to describe the emotion you feel.

Experience 1

Any day

The emotions I felt: ....

Where & When: ....

What medium am I using: ....
(text message, auidio call, video call...)

My brief description about what happened

I think this moment is woth recording because...

e.g., The way my mom replied is very active. However, her voice is quite calm and kind of tiring. I am not sure if she is really happy about my choice. It's quite ambiguous.

Experience 2

Any day

The emotions I felt: ....

Where & When: ....

What medium am I using: ....
(text message, auidio call, video call...)

My brief description about what happened

I think this moment is woth recording because...

e.g., The way my mom replied is very active. However, her voice is quite calm and kind of tiring. I am not sure if she is really happy about my choice. It's quite ambiguous.

CLEAR

The person I **can always** get his or her feelings when communicating remotely.

Day 5

He or she is my: ☐ friend ☐ family ☐ partner ☐ relative

We live in: ☐ the same city ☐ different cities ☐ different countries

We usually comunicate through: ☐ text message ☐ audio call ☐ video call ☐ others (please also write down what it is)

We usually comunicate in: 6:00 12:00 18:00 24:00

When communicating, I'm usually at: ☐ home ☐ work/study place ☐ public space (e.g., street, transport, mall) ☐ others (please also write down what it is)

CONFUSED

The person I frequently **feel difficult** to get his or her emotional states during a remote communication.

Day 4

He or she is my: ☐ friend ☐ family ☐ partner ☐ relative

We live in: ☐ the same city ☐ different cities ☐ different countries

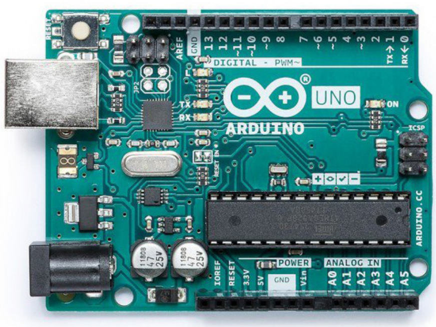
We usually comunicate through: ☐ text message ☐ audio call ☐ video call ☐ others (please also write down what it is)

We usually comunicate in: 6:00 12:00 18:00 24:00

When communicating, I'm usually at: ☐ home ☐ work/study place ☐ public space (e.g., street, transport, mall) ☐ others (please also write down what it is)

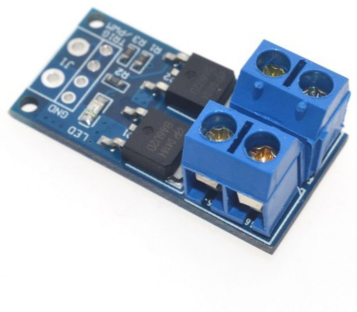
Appendix 2

Components used for the demo version



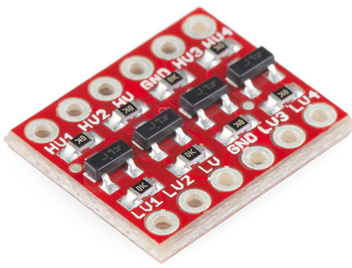
Arduino Uno

Grove - 2-Channel SPDT Relay

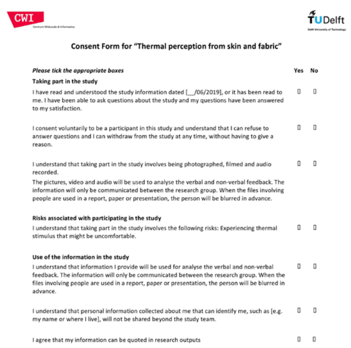


15A 400W MOSFET PWM MODULE

Adafruit 1-Wire Thermocouple Amplifier - MAX31850K



SparkFun Logic Level Converter - Bi-Directional



CWI Centrum Wiskunde & Informatica

TUDelft Delft University of Technology

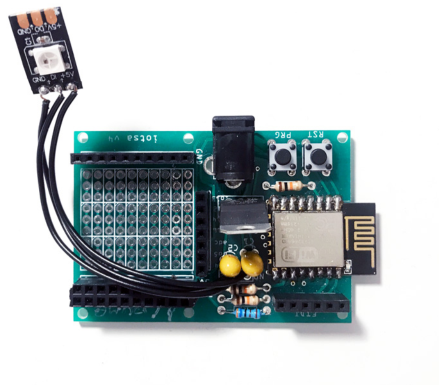
Consent Form for "Thermal perception from skin and fabric"

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated [__/06/2019], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	▯	▯
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	▯	▯
I understand that taking part in the study involves being photographed, filmed and audio recorded. The pictures, video and audio will be used to analyse the verbal and non-verbal feedback. The information will only be communicated between the research group. When the files involving people are used in a report, paper or presentation, the person will be blurred in advance.	▯	▯
Risks associated with participating in the study		
I understand that taking part in the study involves the following risks: Experiencing thermal stimulus that might be uncomfortable.	▯	▯
Use of the information in the study		
I understand that information I provide will be used for analyse the verbal and non-verbal feedback. The information will only be communicated between the research group. When the files involving people are used in a report, paper or presentation, the person will be blurred in advance.	▯	▯
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	▯	▯
I agree that my information can be quoted in research outputs	▯	▯

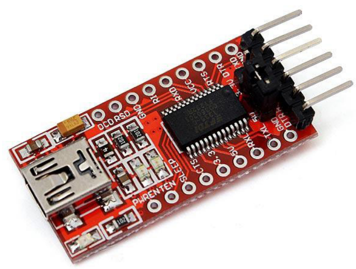
micro tact push button

Appendix 3

Components used for the prototype for experiment

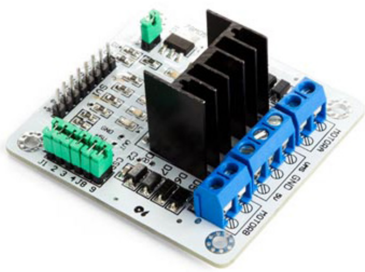


Iotsa board with wifi chip

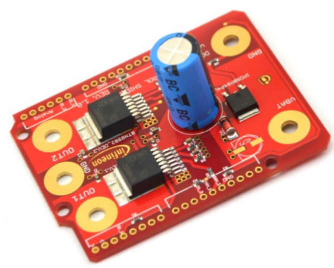


FT232RL USB to TTL
serial adaptor

Adafruit 1-Wire
Thermocouple Amplifier -
MAX31850K



L298N Dual Bridge
DC & Stepper motor
controller board
(used for experiment one)



dc motor control shield
with btn8982 dev.1
(used for experiment two)

Appendix 4

Code (for experiment two)

The main loop of the code for two experiments are the same except for some parameters like the PID value for "Intervention point". The detailed information is already shown in *Chapter Prototyping* and *Chapter Experiment two. Therefore, here I only present the code for experiment two.*

```
#include <PID_v1.h>
#include <DallasTemperature.h>
#include <OneWire.h>

#include <iotsa.h>
#include <iotsaWifi.h>
#include <iotsaOta.h>
#include <iotsaLed.h>

#include "modules/pidconfigmod.h"
#include "modules/setpointmod.h"
#include "modules/temperaturemod.h"

// Constants for pins
#define PID_OUTPUT 13
#define PID_COOL 4
#define PID_WARM 5
#define TEMP_PROBE 14

// Delay for reading the digital temp sensor in ms
#define TEMP_READ_DELAY 100

// PID settings
int KP = 165;
int KI = 2;
int KD = 0;

// Initialise iotsa
IotsaApplication app("Iotsa PID controller");
IotsaWifiMod wifiMod(app);
IotsaOtaMod otaMod(app);
IotsaLedMod ledMod(app, LED_OUTPUT);
```

```
// Initialise PID
double temperature, setPoint, outputVal;
PID *myPID;

// Initialise temperature prove
OneWire oneWire(TEMP_PROBE);
DallasTemperature temperatureSensors(&oneWire);

// Track time of last clock update
unsigned long lastTempUpdate, lastDebugUpdate;

// Instantiate module and install it in the application
SetPointMod setPointMod(app, setPoint);

// Initialise the config mod and register it with the application
PIDConfigMod configMod(app, KP, KI, KD);

// Initialise the temperature mod and register it with the application
TemperatureMod temperatureMod(app, temperature);

/**
 * Updates the global variable `temperature` in a interval given by the
 * constant `TEMP_READ_DELAY`. Returns true if the variable was updated, false
 * otherwise.
 **/
bool updateTemperature() {
  if ((millis() - lastTempUpdate) > TEMP_READ_DELAY) {
    // Get temp reading
    temperatureSensors.requestTemperatures();
    temperature = temperatureSensors.getTempCByIndex(0);
    lastTempUpdate = millis();
    // Request reading for next time

    return true;
  }

  return false;
}

/**
 * Initialises the output pins, the serial connection, the initial `setPoint`,
 * the temperature sensor and sets up initial values for the PID.
 **/
```

```
void setup() {
  Serial.begin(9600);

  // Initialise output pins
  pinMode(PID_OUTPUT, OUTPUT);
  pinMode(PID_COOL, OUTPUT);
  pinMode(PID_WARM, OUTPUT);

  // Set up iotsa application
  app.setup();
  app.serverSetup();

 // Initialise temperature sensors
  temperatureSensors.begin();
  temperatureSensors.requestTemperatures();

  // Wait until we got a reading from the temperature sensors
  while (!updateTemperature()) {}

  // Print values that are used to initialise PID
  Serial.print("Initialising PID with values: ");
  Serial.print(KP);
  Serial.print(",");
  Serial.print(KI);
  Serial.print(",");
  Serial.println(KD);

  // Initialise initial target temperature to 32 degrees
  setPoint = 32;

  // Initialise the PID
  myPID = new PID(&temperature, &outputVal, &setPoint, KP, KI, KD, DIRECT);
  myPID->SetOutputLimits(-1023, 1023);
  myPID->SetMode(AUTOMATIC);
}

/**
 * Runs repeatedly after initialisation. Reads current temperature from the
 * temperature sensor, waits for command input from the serial port to update
 * the variable `setPoint` and calculates values for adjusting the PID and thus
 * the temperature of the Peltier element. Prints debug output after each
 * iteration.
 **/
void loop() {
  // Main loop for iotsa application
  app.loop();

  // Update temperature reading every so often
  updateTemperature();

  // Set tuning params for PID in case they have changed
  myPID->SetTunings(KP, KI, KD);
```

```
 // Compute output value for PID based on `temperature` and `setPoint`
 myPID->Compute();
 if (setPoint == 38.00) {
  KI = 2;
  KP = 1000;
  KD = 0;
  if (temperature <= 35.00) {
  outputVal = 1023;
  }
  else if ((temperature > 35.00)&&(temperature < 37.75)) {
  outputVal = 300;
  }

else if ((temperature >= 37.75)&&(temperature <= 38)) {
  outputVal = 0;
  }
 }
 else if (setPoint == 28.00) {
  KI = 2;
  KP = 400;
  KD = 0;
  if (temperature >= 28.75) {
  outputVal = -1023;
  }
  else if ((temperature < 28.75)&&(temperature >= 28.25)) {
  outputVal = -900;
  }
  else if ((temperature < 28.25)&&(temperature >= 28)) {
  outputVal = 0;
  }
 }
 else if (setPoint == 32.00) {
  if ((temperature > 33.00)||(temperature < 31.00)) {
  KI = 2;
  KP = 165;
  KD = 0;
  } else {
  KI = 2;
  KP = 145;
  KD = 0;
  }
 }

 // Start heating if calculated `outputVal` is greater than or equal to zero
 if (outputVal >= 0) {
  // heating
  digitalWrite(PID_COOL, LOW);
  digitalWrite(PID_WARM, HIGH);
  if ((outputVal > 70)&&(outputVal < 250)) {
   outputVal = 250;
  }
  if ((outputVal >= 0)&&(outputVal <= 70)) {
```

```
      outputVal = 0;
    }

  } else {
    // cooling
    digitalWrite(PID_COOL, HIGH);
    digitalWrite(PID_WARM, LOW);
    if ((outputVal < -70)&&(outputVal > -250)) {
      outputVal = -250;
    }
    if ((outputVal >= -70)&&(outputVal < 0)) {
      outputVal = 0;
    }

}

  // Write output value to PID output
  if (temperature > 44.00) {
    outputVal = 0;
    analogWrite(PID_OUTPUT, int(abs(outputVal)));
  } else {
    analogWrite(PID_OUTPUT, int(abs(outputVal)));
  }

   double gap = setPoint - temperature;

  if ((millis() - lastDebugUpdate) > TEMP_READ_DELAY) {

    // Debug output
    Serial.print("Temperature is: ");
    Serial.print(temperature);
    Serial.print(" setpoint ");
    Serial.print(setPoint);
    Serial.print(" gap ");
    Serial.print(gap);
    Serial.print(" outputVal ");
    Serial.print(outputVal);
    Serial.print(" PID ");
    Serial.print(KP);
    Serial.print(",");
    Serial.print(KI);
    Serial.print(",");
    Serial.println(KD);

    lastDebugUpdate = millis();
  }
}
```

Appendix 5

Paper forms for experiment one

Information form

CWI Centrum Wiskunde & Informatica

TUDelft Delft University of Technology

Information about the research
"Thermal perception from skin and fabric"

Purpose:

The purpose of this study is to find the recognizable and acceptable on-body thermal stimuli with the suitable contact medium (fabric or naked skin). The findings will be used for a thesis project exploring augmenting ambiguous voice messages through thermal stimuli on garments. The project is under the supervision of scholars from TU Delft and Centrum Wiskunde & Informatica (CWI). The study is conducted in the form of a controlled experiment.

Benefits and risks of participating:

The main risk is that you might feel uncomfortable about the on-body thermal stimulus (32±3°C, 32±6°C). The temperature range is generally harmless for people. However, you need to wear a T-shirt built by the student researcher which will add thermal stimuli on your upper chest. But you can stop the test and leave at any time if you do not want to continue. You will be rewarded with a 10 euro voucher for participating.

Personal information collected:

During the study, your basic information (gender, age, height, weight) will be collected. Verbal and non-verbal feedback will be collected through in-app likert scales and an audio recorder. The data will be used for analysis by the student researcher. An Empatica E4 device will be used to measure your skin temperature at the beginning of the test. Only the research group can get access to the data collected from you.

During the research, your personal information will not be shown to anyone other than the research group. The data will be stored on the server of (CWI). Only the researchers involved in this project have the access to the data. Some pictures, frames or subjective feedback about you might be used in a report, paper, presentation or portfolio. In those cases, your figure will be blurred in advance (if you choose).

In case you want to see the result of your experiment, you can refer to the student researcher for access.

Below you can find the contact of the student researcher:

Xingyu Yang – X.Yang-6@student.tudelft.nl

Consent form

CWI Centrum Wiskunde & Informatica

TUDelft Delft University of Technology

Consent Form for "Thermal perception from skin and fabric"

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [__/06/2019], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	▯	▯
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	▯	▯
I understand that taking part in the study involves being photographed, filmed and audio recorded. The pictures, video and audio will be used to analyse the verbal and non-verbal feedback. The information will only be communicated between the research group. When the files involving people are used in a report, paper or presentation, the person will be blurred in advance.	▯	▯
Risks associated with participating in the study		
I understand that taking part in the study involves the following risks: Experiencing thermal stimulus that might be uncomfortable.	▯	▯
Use of the information in the study		
I understand that information I provide will be used for analyse the verbal and non-verbal feedback. The information will only be communicated between the research group. When the files involving people are used in a report, paper or presentation, the person will be blurred in advance.	▯	▯
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	▯	▯
I agree that my information can be quoted in research outputs	▯	▯
Future use and reuse of the information by others		
I give permission for the data (gender, age, height, weight, skin temperature, verbal and nonverbal feedback) that I provide to be archived in TU Delft repository so it can be used for future research and learning.	▯	▯

Signatures

____________________	____________________	________
Name of participant [printed]	Signature	Date

Participant information form 1

Participant Information Form

Age _______

Gender (leave blank if you would rather not say): ____________________

Profession (or current studies) ________________________________

Height: _________________________

Weight: ________________________

"I hereby verify that the information provided on this form is correct to the best of my knowledge."

Date: ____________________

Signature: ____________________

Participant information form 2

#: ____

ID: _____________________________

Counter: _______________________

Room temperature: ___________

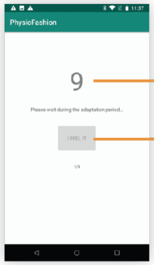
Skin temperature: ______________

Application instruction

Application Instruction

This will be given to you by the researcher

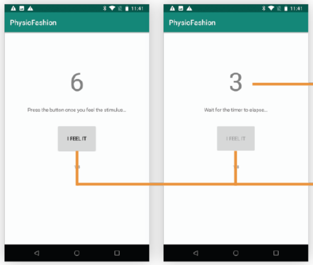
Step1/ Basic info.
Input your participant ID, the number of the first thermal condition and the condition of fabric



The countdown of the adaptation duration

The button is used to record the moment you start to feel the thermal stimulus. The button is unclickable in this step.

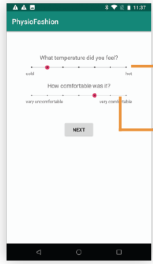
Step2/ Adaptation
Adapt your skin temperature to the baseline temperature of 32°C. The adaptation lasts for 10 seconds.



The countdown of the thermal stimulus duration

Press the button as soon as you feel the thermal stimulus. After clicking, the button becomes unclickable, you wait until the thermal stimulus ends.

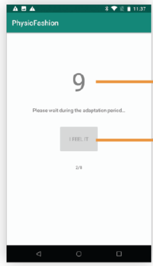
Step3/ Experiencing thermal stimuli
The thermal stimulus is added for 7 seconds from the baseline temperature (32°C).



From "cold" to "neutral" to "hot"

From "very uncomfort-able" to "no difference from no thermal stimulus" to "very comfortable"

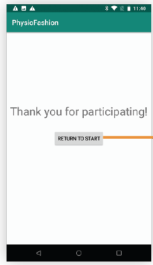
Step4/ Ratings
Input your ratings in terms of the intensity and comfort of the thermal stimulus.



The countdown of the adaptation duration

The button is used to record the moment you start to feel the thermal stimulus. The button is unclickable in this step.

Step2/ again
Enter the round for the second thermal stimulus



Go back to the login page to start the second part (with or without fabric)

Final step/ Start over
Enter the final page after finishing all the eight stimuli.

Appendix 6

Paper forms for experiment two

Information form

CWI
Centrum Wiskunde & Informatica

TU Delft
Delft University of Technology

Information about the research
"Thermal voice messages"

Purpose:

The purpose of this study is to explore how thermal stimuli can affect voice messages. The findings will be used for a thesis project exploring augmenting voice messages with thermal stimulation embedded on garments. The project is under the supervision of scholars from TU Delft and Centrum Wiskunde & Informatica (CWI). The study is conducted in the form of a controlled experiment.

Benefits and risks of participating:

The main risk is that you might feel uncomfortable about the on-body thermal stimuli (38°C, 28°C). The temperature range is generally harmless for people. However, you need to wear a T-shirt built by the student researcher which will add thermal stimuli on your upper chest. You can stop the test and leave at any time if you do not want to continue. You will be rewarded with a 10 euro voucher for participating.

Personal information collected:

During the study, your basic information (gender, age, profession, height, weight) will be collected. Verbal and non-verbal feedback will be collected through in-app Likert scales and an audio recorder. The data will be used for analysis by the student researcher. An Empatica E4 device will be used to measure your current skin temperature at the beginning of the test. Only the research group can get access to the data collected from you.

During the research, your personal information will not be shown to anyone other than the research group. The data will be stored on the server of CWI. Only the researchers involved in this project have access to the data. Some pictures, frames or subjective feedback from you might be used in a report, paper, presentation or portfolio. In those cases, you will be asked for permission, and by default your figure will be blurred (unless you choose otherwise).

In case you want to see the result of your experiment, you can refer to the student researcher for access.

Below you can find the contact of the student researcher:

Xingyu Yang – X.Yang-6@student.tudelft.nl

Consent form

CWI
Centrum Wiskunde & Informatica

TU Delft
Delft University of Technology

Consent Form for "Thermal perception from skin and fabric"

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [__/07/2019], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves being photographed, filmed and audio recorded. The pictures, video and audio will be used to analyse the verbal and non-verbal feedback. The information will only be communicated between the research group. When the files involving people are used in a report, paper or presentation, the person will be blurred in advance.	☐	☐
Risks associated with participating in the study		
I understand that taking part in the study involves the following risks: Experiencing thermal stimulus that might be uncomfortable.	☐	☐
Use of the information in the study		
I understand that information I provide will be used for analyse the verbal and non-verbal feedback. The information will only be communicated between the research group. When the files involving people are used in a report, paper or presentation, the person will be blurred in advance.	☐	☐
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	☐	☐
I agree that my information can be quoted in research outputs	☐	☐
Future use and reuse of the information by others		
I give permission for the data (gender, age, height, weight, skin temperature, verbal and nonverbal feedback) that I provide to be archived in TU Delft repository so it can be used for future research and learning.	☐	☐

Signatures

______________________	______________________	________
Name of participant [printed]	Signature	Date

Participant information form 1

CWI
Centrum Wiskunde & Informatica

TUDelft
Delft University of Technology

Participant Information Form

Age: _______

Gender (leave blank if you would rather not say): ____________________

Profession (or current studies): _________________________________

Height: _________________________

Weight: ________________________

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)? Choose one answer below:

1. Never **2. Rarely** **3. Sometimes** **4. Frequently** **5. Daily**

"I hereby verify that the information provided on this form is correct to the best of my knowledge."

Date: ____________________ **Signature:** ____________________

Participant information form 2

CWI
Centrum Wiskunde & Informatica

TUDelft
Delft University of Technology

#: ____

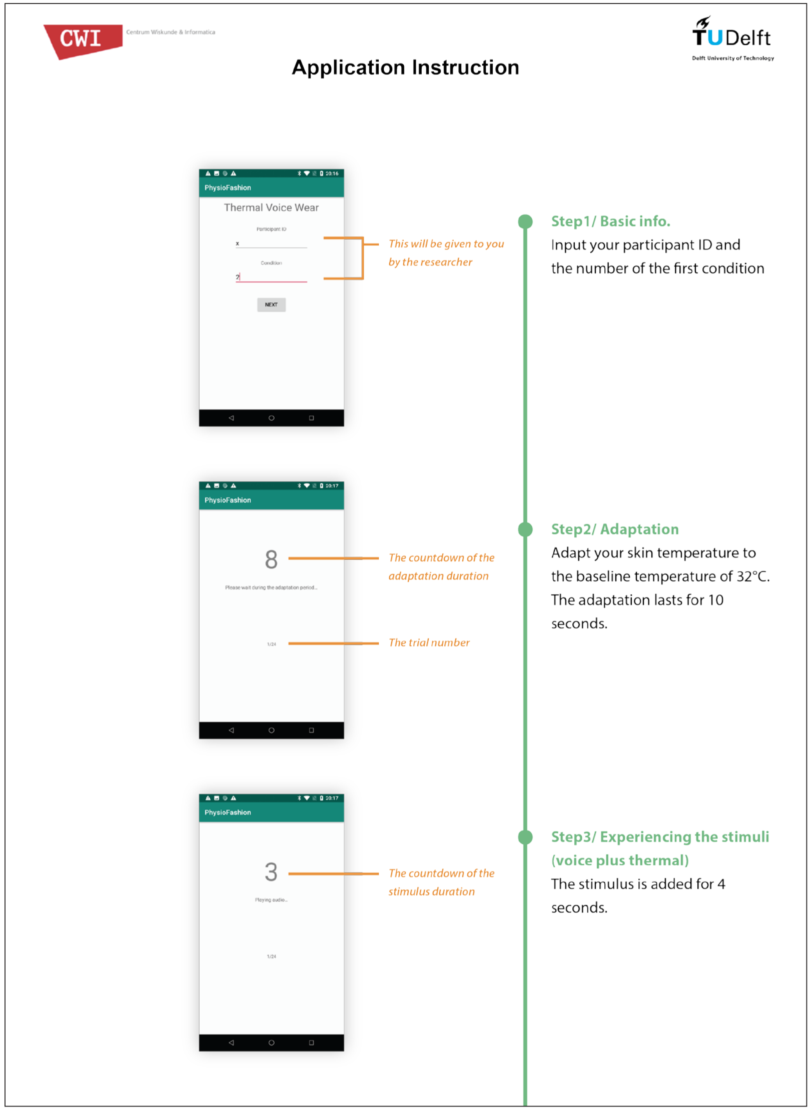
ID: _____________________________

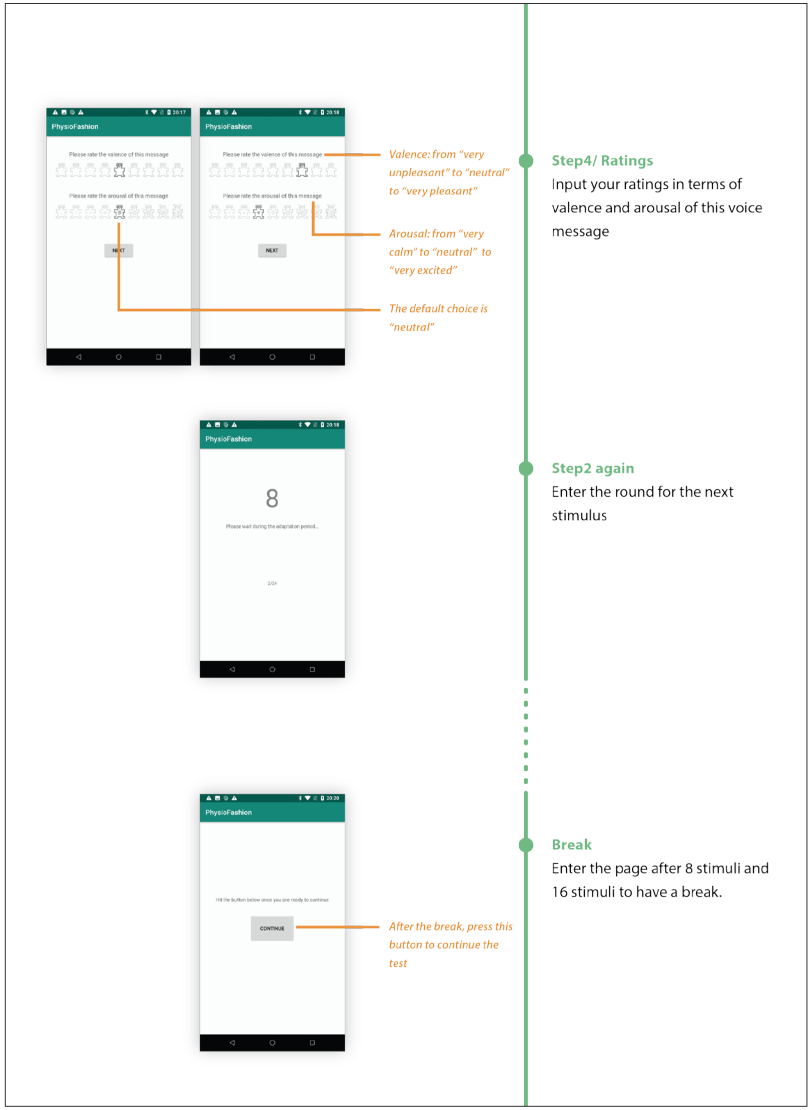
Counter: _______________________

Room temperature: ___________

Skin temperature: _____________

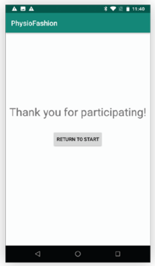
Application instruction





Application about valence and arousal

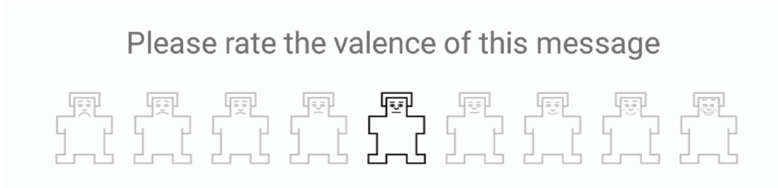
Step2 again
Enter the round for the next stimulus



Final step/ Start over
Enter the final page after finishing all the 24 stimuli.

Valence

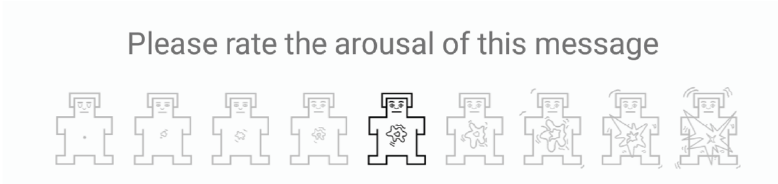
how pleasant the speaker is based on the voice and the thermal stimulus



Very unpleasant | Neutral | Very pleasant

Arousal

how excited the speaker is based on the voice and the thermal stimulus



Very calm | Neutral | Very excited

Appendix 7

Participant profile and feedback/ experiment one

Because subjective intensity and comfort are collected in the format of quantitative data. The questions for the semi-structured interview are to collect supplements and open feedback. Therefore, participants are asked to recall the experience of thermal stimulus and talked about the difference between "warm" and "cold", "high intensity" and "low intensity", "with fabric" and "without fabric". They are also encouraged to share open feedback about the experience, the device or the mental acceptance to the thermal stimulus.

P1

Age: 24

Gender: male

Profession (or current studies): student (information systems)

Height: 190cm

Weight: 80kg

First condition: low intensity cold, without fabric

Room temperature: 23.2°C

Skin temperature: 32.49°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
1	1	1	cool	3	0	1560947664.13	1560947667.64	1	5
2	2	1	warm	3	0	1560947695.31	1560947709.65	3	6
3	3	1	cool	6	0	1560947742.91	1560947750.75	0	5
4	4	1	cool	3	0	1560947770.03	1560947777.27	0	5
5	5	1	warm	3	0	1560947796.46	1560947808.32	2	6
6	6	1	warm	6	0	1560947841.58	1560947847.6	5	5
7	7	1	cool	6	0	1560947897.55	1560947916.84	2	3
8	8	1	warm	6	0	1560947931.11	1560947935.35	6	3
9	1	1	cool	3	1	1560948399.72	1560948410.13	2	6
10	2	1	warm	3	1	1560948426.58	1560948441.87	3	6
11	3	1	cool	6	1	1560948459.7	1560948469.35	2	5
12	4	1	cool	3	1	1560948487.55	1560948493.72	1	5
13	5	1	warm	6	1	1560948514.16	1560948541.58	3	6
14	6	1	cool	6	1	1560948556.24	1560948568.79	2	6
15	7	1	warm	3	1	1560948586.87	1560948606.47	3	6
16	8	1	warm	6	1	1560948622.03	1560948646.56	3	6

Quotes:

" The stimulus through silk is definitely more subtle. It definitely makes a difference. For some reason, I didn't feel any of them warm. "

" I didn't notice much difference about the touching area. The area of the part is already quite small. For the extreme temperature with no silk, it definitely started local and expanded a little bit. While with the pat, I didn't notice that. But again, with the pat, I didn't notice any extreme, so again I don't know. "

" The fact that I do have quite a little bit of chest hair makes the perception different. "

P2

Age: 25

Gender: male

Profession (or current studies): master student

Height: 178cm

Weight: 73kg

First condition: high intensity cold, without fabric

Room temperature: 22.6°C

Skin temperature: 31.51°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
65	1	2	cool	6	0	1561040364.23	1561040381.48	3	3
66	2	2	cool	6	0	1561040415.79	1561040423.79	4	4
67	3	2	warm	3	0	1561040463.07	1561040467.31	5	4
68	4	2	warm	3	0	1561040490.2	1561040494.76	5	4
69	5	2	warm	6	0	1561040533.99	1561040538.6	5	4
70	6	2	cool	3	0	1561040566.11	1561040568.16	6	4
71	7	2	cool	3	0	1561040593.04	1561040596.62	5	1
72	8	2	warm	6	0	1561040630	1561040635.33	4	4
73	1	2	cool	6	1	1561041397.63	1561041399.76	2	3
74	2	2	cool	6	1	1561041424.15	1561041428.08	2	3
75	3	2	warm	6	1	1561041447.62	1561041453.5	4	3
76	4	2	cool	3	1	1561041472.85	1561041476.34	2	3
77	5	2	warm	6	1	1561041495.77	1561041502.56	4	3
78	6	2	warm	3	1	1561041519.69	1561041530.78	3	3
79	7	2	warm	3	1	1561041545.81	1561041566.24	3	3
80	8	2	cool	3	1	1561041589.84	1561041593.72	2	3

Quotes:

" For the trial without clothes, I didn't feel any cold ones. "

" The first ones felt on the naked skin felt a bit more intense I guess, which makes sense. The ones with clothes are more subtle for sure. But that's more for the warm ones. Because for the cold ones, I didn't feel anything without the clothes. "

" Without the clothes, a couple of the warm ones might be too intense. That might not be comfortable for a long time I think. I didn't feel the cold ones without clothes. But with clothes, it's fine. It's refreshing I guess. And again, with clothes, all the warm ones are very subtle. They are harder to notice. "

P3

Age: 28

Gender: male

Profession (or current studies): PhD student

Height: 175cm

Weight: 70kg

First condition: low intensity warm, no fabric

Room temperature: 23.0°C

Skin temperature: 31.19°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
81	1	3	warm	3	0	1561044278.35	1561044298.02	3	3
82	2	3	warm	3	0	1561044312.43	1561044319.3	4	3
83	3	3	cool	6	0	1561044339.82	1561044341.47	0	4
84	4	3	warm	6	0	1561044367.28	1561044376.91	2	4
85	5	3	cool	3	0	1561044396.09	1561044397.5	0	4
86	6	3	cool	3	0	1561044425.84	1561044427.74	1	4
87	7	3	cool	6	0	1561044451.64	1561044453.95	1	4
88	8	3	warm	6	0	1561044482.59	1561044487.15	5	5
89	1	3	warm	3	1	1561044930.3	1561044947.3	3	3
90	2	3	cool	3	1	1561044961.65	1561044968.28	2	4
91	3	3	warm	3	1	1561044985.62	1561044989.99	4	5
92	4	3	cool	6	1	1561045012.81	1561045018.52	2	5
93	5	3	cool	3	1	1561045036.2	1561045041.92	2	5
94	6	3	warm	6	1	1561045060.63	1561045073.4	3	3
95	7	3	cool	6	1	1561045086.52	1561045092.78	2	5
96	8	3	warm	6	1	1561045110.34	1561045121.88	3	3

Quotes:

" I always feel the cold constantly. The warm stimulus can be more extreme. I can't feel it. "

" The stimulus through fabric is less subtle and more comfortable. "

" In both cases, I feel the stimulus only at the point. It doesn't spread. "

P4

Age: 25

Gender: male

Profession (or current studies): student

Height: 170cm

Weight: 62kg

First condition: high intensity warm, with fabric

Room temperature: 23.2°C

Skin temperature: 30.27°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
97	1	4	warm	6	0	1561125063.33	1561125064.89	5	1
98	2	4	warm	3	0	1561125092.49	1561125095.79	4	4
99	3	4	cool	6	0	1561125120.2	1561125122.66	0	1
100	4	4	cool	3	0	1561125151.48	1561125153.44	2	5
101	5	4	cool	3	0	1561125186.63	1561125188.52	1	5
102	6	4	cool	6	0	1561125217.49	1561125219.05	0	2
103	7	4	warm	6	0	1561125247.79	1561125249.94	6	1
104	8	4	warm	3	0	1561125279.08	1561125283.56	4	6
105	1	4	warm	6	1	1561124189.7	1561124196.27	4	6
106	2	4	cool	3	1	1561124226.55	1561124228.65	2	5
107	3	4	cool	6	1	1561124257.88	1561124260.8	2	5
108	4	4	warm	6	1	1561124290.77	1561124294.74	4	6
109	5	4	warm	3	1	1561124319.58	1561124328.88	4	6
110	6	4	cool	6	1	1561124356.98	1561124360.01	1	5
111	7	4	warm	3	1	1561124390.55	1561124400.47	3	3
112	8	4	cool	3	1	1561124481.18	1561124482.58	2	6

Quotes:

" Cold is faster and more impressive. It's also more acceptable and comfortable. "

" The warm stimulus is only impressive through naked skin. If experienced through silk, it's more comfortable. "

" When experienced through fabric, the warm stimulus is not easy to detect. I can make sure it's warm but it's hard to tell the intensity. "

" The fabric has less effect on cold stimulus compared to the warm ones. "

" The medal (Peltier element) feels sticky. It doesn't breathe. "

P5

Age: 25

Gender: male

Profession (or current studies): student

Height: 178cm

Weight: 80kg

First condition: low intensity warm, with fabric

Room temperature: 23.5°C

Skin temperature: 32.41°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
113	1	5	warm	3	0	1561129673.61	1561129691.83	4	3
114	2	5	warm	6	0	1561129710.58	1561129715.27	5	4
115	3	5	cool	6	0	1561129745.29	1561129748.17	0	4
116	4	5	cool	3	0	1561129769.84	1561129776.8	1	2
117	5	5	warm	6	0	1561129793.02	1561129799.47	5	2
118	6	5	cool	3	0	1561129820.82	1561129825.6	2	2
119	7	5	cool	6	0	1561129844.44	1561129844.88	1	2
120	8	5	warm	3	0	1561129869.88	1561129877.76	4	2
121	1	5	warm	3	1	1561128863.62	1561128875.74	2	2
122	2	5	warm	6	1	1561128914.22	1561128931.81	3	3
123	3	5	cool	3	1	1561128948.19	1561128955.49	2	3
124	4	5	cool	3	1	1561128974.78	1561128982.39	2	2
125	5	5	warm	6	1	1561128996.4	1561129009.99	2	2
126	6	5	cool	6	1	1561129050.82	1561129058.88	1	1
127	7	5	warm	3	1	1561129074.89	1561129086.17	2	2
128	8	5	cool	6	1	1561129102.92	1561129112.96	1	2

Quotes:

" The stimuli on skin are more intense. I can feel the stimulus faster. "

" With a piece of fabric, the stimulus feels more gentle and comfortable. The warm stimulus is too difficult to detect with fabric. "

" Adding a piece of silk makes the device more acceptable. I felt safer with the fabric on. Keeping the metal (Peltier element) attached to skin directly is not good. It feels like doing experiment. "

P6

Age: 25

Gender: male

Profession (or current studies): study

Height: 173cm

Weight: 63kg

First condition: high intensity warm, with fabric

Room temperature: 22.7°C

Skin temperature: 34.84°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
129	1	6	cool	6	0	1561396028.95	1561396038.24	1	3
130	2	6	cool	3	0	1561396058.3	1561396068.12	4	3
131	3	6	warm	6	0	1561396084.23	1561396089.3	5	2
132	4	6	warm	6	0	1561396112.65	1561396119.18	4	3
133	5	6	cool	6	0	1561396133.48	1561396141.31	2	3
134	6	6	warm	3	0	1561396157.04	1561396164.15	5	2
135	7	6	cool	3	0	1561396184.16	1561396191.13	4	3
136	8	6	warm	3	0	1561396205.55	1561396216.14	3	3
137	1	6	cool	6	1	1561393701.12	1561393715.91	4	3
138	2	6	warm	3	1	1561393745.13	1561393754.52	5	3
139	3	6	warm	6	1	1561393771.18	1561393795.41	4	2
140	4	6	warm	6	1	1561393816.47	1561393823.21	5	2
141	5	6	cool	6	1	1561393841.99	1561393848.16	2	3
142	6	6	cool	3	1	1561393874.51	1561393884.94	3	3
143	7	6	warm	3	1	1561393899.89	1561393910.56	2	3
144	8	6	cool	3	1	1561393927.61	1561393934.91	1	3

Quotes:

" The stimuli on skin are more intense. With a fabric, the stimulus is not very clear. The temperature doesn't go extreme with textiles, which makes it a little bit more comfortable. "

" For warming, I feel the heat spreads to other parts of my body. For cooling, the stimulus feels like a point. Heating feels like on an area. "

" For comfort, I feel the low intensity is always comfortable. Only when it comes to high intensity, for both warm and cold, I feel uncomfortable. But for the same intensity, I feel the comfort for warm and cold are similar. "

P7

Age: 32

Gender: female

Profession (or current studies): post-doc

Height: 163cm

Weight: 59kg

First condition: low intensity cold, without fabric

Room temperature: 23.0°C

Skin temperature: 28.81°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
145	1	7	cool	3	0	1560950787.02	1560950816.36	2	3
146	2	7	cool	6	0	1560950859.21	1560950862.3	1	3
147	3	7	cool	6	0	1560950909.83	1560950912.61	1	3
148	4	7	warm	3	0	1560950941.62	1560950943.77	5	3
149	5	7	warm	3	0	1560950969.15	1560950971.59	4	3
150	6	7	cool	3	0	1560950994.74	1560950997.21	1	3
151	7	7	warm	6	0	1560951031.38	1560951034.79	5	2
152	8	7	warm	6	0	1560951061.62	1560951063.77	5	3
153	1	7	cool	3	1	1560951647.76	1560951651.67	2	4
154	2	7	cool	6	1	1560951678.61	1560951683.06	2	4
155	3	7	warm	3	1	1560951702.52	1560951711.43	3	3
156	4	7	warm	3	1	1560951729.53	1560951735.91	4	4
157	5	7	warm	6	1	1560951772.23	1560951778.77	4	5
158	6	7	warm	6	1	1560951800.82	1560951806.88	4	4
159	7	7	cool	6	1	1560951852.4	1560951855.97	1	5
160	8	7	cool	3	1	1560951883.36	1560951900.69	3	3

Quotes:

" The stimulus on skin, I can feel it more quickly. It feels more extreme. I can feel it's more irritating, which I didn't really like."

" Even I know it wasn't like a very strong stimulus, but I think having the silk just make me less worried somehow that I was gonna burn myself or irritate myself. So I like that I mentally having that. "

" When it's cooling down, I can pretty quickly feel it's cooling down. When it's heating up, it's harder for me to tell it. It took longer. "

P8

Age: 24

Gender: female

Profession (or current studies): Industrial design

Height: 165cm

Weight: 47kg

First condition: high intensity cold, without fabric

Room temperature: 22.8°C

Skin temperature: 27.73°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
161	1	8	cool	6	0	1560954031.37	1560954032.82	2	3
162	2	8	warm	3	0	1560954071	1560954073.49	4	4
163	3	8	warm	3	0	1560954107.41	1560954110.57	4	4
164	4	8	warm	6	0	1560954140.83	1560954142.53	4	3
165	5	8	cool	3	0	1560954181.09	1560954182.41	2	2
166	6	8	cool	3	0	1560954237.5	1560954240.07	2	4
167	7	8	warm	6	0	1560954283.43	1560954285.95	4	4
168	8	8	cool	6	0	1560954320.36	1560954323.27	1	2
169	1	8	cool	6	1	1560954901.41	1560954905.14	2	3
170	2	8	warm	6	1	1560954937.91	1560954941.91	4	5
171	3	8	warm	6	1	1560954962.95	1560954968.84	4	5
172	4	8	cool	6	1	1560955003.9	1560955006.18	1	3
173	5	8	warm	3	1	1560955037.2	1560955044.03	4	5
174	6	8	cool	3	1	1560955069.25	1560955072.07	2	4
175	7	8	cool	3	1	1560955098.82	1560955102.37	2	3
176	8	8	warm	3	1	1560955122.94	1560955127.62	4	5

Quotes:

" No matter having fabric or not, warm stimulus is always more comfortable than the cold ones. "

" Adding a piece of fabric makes it little bit more comfortable. "

" For the warm stimulus, I can feel the difference between low and high intensity. For the cold one, I can't feel the difference. Probably the cold stimulus is too intense for me. "

" If the temperature changes intensely, I have a low acceptance. If it changes gradually, I have higher acceptance. "

P9

Age: 32

Gender: female

Profession (or current studies): Researcher

Height: 173cm

Weight: 48kg

First condition: low intensity warm, without fabric

Room temperature: 23.0°C

Skin temperature: 30.79°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
177	1	9	warm	3	0	1561037189.97	1561037195.94	4	3
178	2	9	cool	6	0	1561037218.65	1561037220.17	0	0
179	3	9	warm	3	0	1561037244.57	1561037247.52	5	4
180	4	9	cool	6	0	1561037273.07	1561037274.44	0	0
181	5	9	warm	6	0	1561037294.72	1561037296.94	6	1
182	6	9	cool	3	0	1561037319.68	1561037321.16	1	2
183	7	9	warm	6	0	1561037343.6	1561037346.49	6	1
184	8	9	cool	3	0	1561037372.71	1561037374.79	2	2
185	1	9	warm	3	1	1561037850.56	1561037856.6	3	3
186	2	9	cool	6	1	1561037871.27	1561037875.87	2	3
187	3	9	warm	3	1	1561037900.49	1561037907.32	3	3
188	4	9	cool	3	1	1561037928.64	1561037930.78	1	2
189	5	9	cool	3	1	1561037950.49	1561037954.14	2	3
190	6	9	warm	6	1	1561037977.12	1561037982.78	5	2
191	7	9	warm	6	1	1561038002.49	1561038008.23	4	3
192	8	9	cool	6	1	1561038030.13	1561038034.04	1	2

Quotes:

" I can feel the process of the temperature change. "

" I'm quite looking forward to the cold stimulus. It's quite refreshing. The cold stimulus takes less time to detect. "

" Adding the fabric makes the stimulus less sharp. The cold one is not that harsh anymore. The warm one gets subtle. "

P10

Age: 24

Gender: female

Profession (or current studies): Design for interaction

Height: 168cm

Weight: 58kg

First condition: high intensity warm, with fabric

Room temperature: 23.3℃

Skin temperature: 33.39℃

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
17	1	10	warm	6	0	1561132761.78	1561132766.45	5	2
18	2	10	cool	3	0	1561132788.18	1561132800.07	3	3
19	3	10	cool	3	0	1561132813.51	1561132824.85	3	3
20	4	10	warm	6	0	1561132837.29	1561132842.62	4	3
21	5	10	cool	6	0	1561132860.18	1561132869.29	2	3
22	6	10	warm	3	0	1561132888.1	1561132898.19	3	3
23	7	10	cool	6	0	1561132910.49	1561132916.12	1	3
24	8	10	warm	3	0	1561132933.25	1561132942.41	3	3
25	1	10	warm	6	1	1561131952.56	1561131972.52	3	3
26	2	10	warm	3	1	1561131993.18	1561132005.36	3	3
27	3	10	cool	6	1	1561132018.27	1561132043.13	3	3
28	4	10	cool	3	1	1561132055.66	1561132055.55	3	3
29	5	10	warm	3	1	1561132077.99	1561132088.37	3	3
30	6	10	cool	6	1	1561132100.53	1561132111.14	3	3
31	7	10	warm	6	1	1561132123.64	1561132123.45	3	3
32	8	10	cool	3	1	1561132143.24	1561132152.51	3	3

Quotes:

" I'm more sensitive to warm stimulus. "

" The feeling of metal (Peltier element) is not good. "

" Adding the fabric makes the stimulus less intense. I can feel nothing with fabric. "

P11

Age: 24

Gender: female

Profession (or current studies): Strategic product design

Height: 162cm

Weight: 51kg

First condition: low intensity cold, with fabric

Room temperature: 23.2°C

Skin temperature: missed

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
33	1	11	cool	3	0	1561384653.62	1561384655.8	2	4
34	2	11	cool	3	0	1561384680.81	1561384682.07	2	2
35	3	11	warm	6	0	1561384707.59	1561384709.12	5	3
36	4	11	cool	6	0	1561384735.1	1561384736.17	2	2
37	5	11	warm	6	0	1561384759.21	1561384761.24	4	4
38	6	11	warm	3	0	1561384784.07	1561384793.28	4	3
39	7	11	warm	3	0	1561384810.59	1561384816.34	4	3
40	8	11	cool	6	0	1561384836.17	1561384837.41	2	2
41	1	11	cool	3	1	1561384653.62	1561384655.8	2	4
42	2	11	cool	3	1	1561384680.81	1561384682.07	2	2
43	3	11	warm	6	1	1561384707.59	1561384709.12	5	3
44	4	11	cool	6	1	1561384735.1	1561384736.17	2	2
45	5	11	warm	6	1	1561384759.21	1561384761.24	4	4
46	6	11	warm	3	1	1561384784.07	1561384793.28	4	3
47	7	11	warm	3	1	1561384810.59	1561384816.34	4	3
48	8	11	cool	6	1	1561384836.17	1561384837.41	2	2

Quotes:

" I felt the stimulus is way more intense without the piece of clothing. I couldn't tolerate that much. If I don't press the next button, it will become very uncomfortable. While with the piece of clothing, I didn't feel this way. "

" When you send the extreme temperatures, for both cold and warm, I feel both were going very fast. And the quality was the same. I can feel both. And regarding the comfort, I felt like that sometimes, since I was wearing something with long sleeves, I felt the cold stimulus was also comfortable while I wasn't expecting that, but only when it was mild cold. Otherwise, it would feel uncomfortable. "

" With the hot , it could get uncomfortable not only because of the temperature on skin, but also because of the perception of my body temperature that was changing. "

" Usually when I feel cold. I mean if I would allow the extreme cold to touch my skin, I would feel like I should just contract myself. Like I think my shoulders go up and I felt more anxious. Of course not in an extreme way because I knew it was temperature but since my body got all contracted, I felt I was in a situation of anxiety. While in the hot, it gets uncomfortable the nit's too much but I don't feel the same reaction of contracting myself. The reaction is mostly of taking that out of my skin. If it's mild hot, I would feel more relaxed. "

P12

Age: 25

Gender: female

Profession (or current studies): Strategic product design

Height: 170cm

Weight: 55kg

First condition: low intensity warm, with fabric

Room temperature: 23.0°C

Skin temperature: 32.49°C

thermalwear_exp_1_responses

	trialNum	participant	condition	intensity	fabricOn	stimulusStarted	stimulusFelt	temperatureFelt	comfortLevel
49	1	12	warm	6	0	1561389365.86	1561389383.34	1	2
50	2	12	cool	3	0	1561389403.27	1561389411.48	1	2
51	3	12	warm	3	0	1561389429.81	1561389448.45	1	2
52	4	12	warm	3	0	1561389469.28	1561389476.35	1	3
53	5	12	cool	6	0	1561389497.37	1561389504.22	4	3
54	6	12	warm	6	0	1561389523.01	1561389528.48	2	2
55	7	12	cool	3	0	1561389545.35	1561389550.83	4	4
56	8	12	cool	6	0	1561389567.57	1561389570.07	2	2
57	1	12	warm	6	1	1561388246.76	1561388253.41	1	1
58	2	12	cool	6	1	1561388296.52	1561388336.81	1	1
59	3	12	warm	3	1	1561388353.48	1561388360.16	2	2
60	4	12	warm	6	1	1561388387.44	1561388404.41	1	2
61	5	12	cool	6	1	1561388423.8	1561388429.91	2	2
62	6	12	cool	3	1	1561388454.91	1561388477.67	3	3
63	7	12	cool	3	1	1561388494.49	1561388498.74	1	2
64	8	12	warm	3	1	1561388521.31	1561388534.34	3	3

Quotes:

" I think I'm more sensitive to cold stimulus than warm ones. I always feel the cold from the plate. I can barely feel the warm stimulus. "

" The thing feels like a metal plate on my chest. I don't like it. It feels strange. "

" Since the participant can't feel thermal stimulus accurately on the middle upper chest. I asked her to move the Peltier element to the right and left sides after the experiment. Then she felt more distinct stimulus. "

Appendix 8

Participant profile and feedback/ experiment two

Because valence and arousal ratings, wearability ratings are collected in the format of quantitative data. The questions for the semi-structured interview are to collect supplements and open feedback.

The following questions are asked during the semi-structured interview:

1. How does warm stimulus affect emotion perception (valence and arousal) from positive messages?
2. How does cold stimulus affect emotion perception (valence and arousal) from positive messages?
3. How does warm stimulus affect emotion perception (valence and arousal) from negative messages?
4. How does cold stimulus affect emotion perception (valence and arousal) from negative messages?
5. Doyou feel valence and arousal are affected differently? If yes, how is it different?
6. Do you have other feedback in terms of the device or the experience?

P1

Age: 32

Gender: female

Profession (or current studies): researcher

Height: 173cm

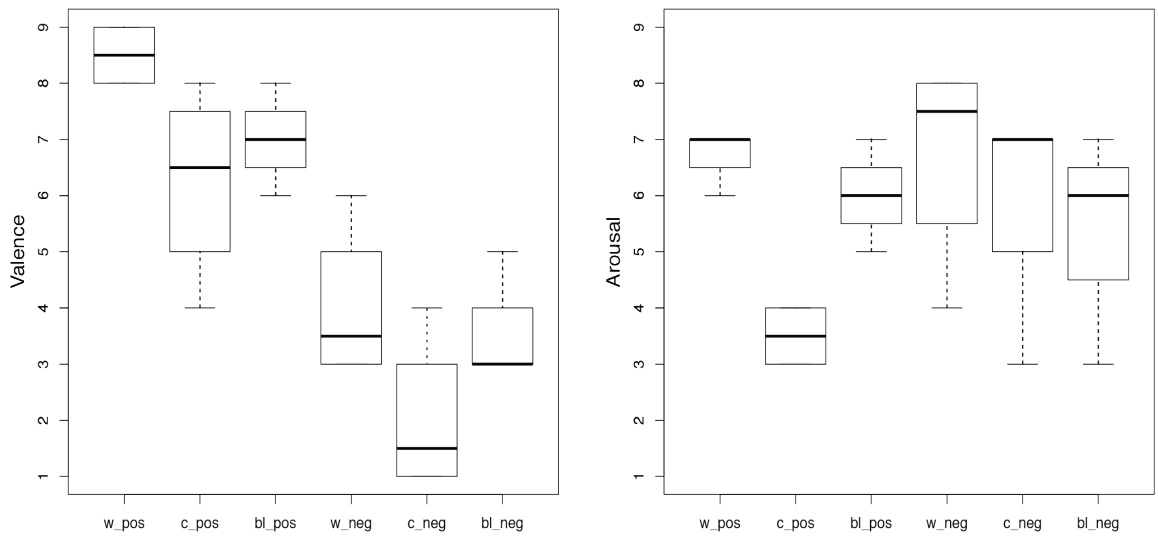
Weight: 48kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Sometimes

Room temperature: 22.8°C

Skin temperature: 31.45°C



P1

Quotes from the semi-structured interview:

Warm-positive: If it's a positive message, the heat will increase the positive feeling.

Warm-negative: If it's a negative message, the heat is quite intense so it might also have negative effects. For example, when the speaker is very angry and I feel the heat, I will feel the negative emotion quite intense.

Cold-positive: When the positive message is played with cold stimulus, I feel it's not that positive anymore.

Cold-negative: When listening to negative messages, receiving cold stimulus might bring the negative to neutral. I felt the cold temperature is cooling the negative emotions down.

Neutral: When there is no thermal stimulus, I might focus more on the voice message itself. For example, "I tried so hard ." is quite neutral for me. I felt it's between complaint and telling others that he has tried his best. But adding the thermal stimulus will affect my detection of the valence.

Valence and arousal: Between valence and arousal, I feel that the effect on valence depends on the specific message. But *for arousal, I tend to feel that the warm stimulus makes the emotion more intense while the cold stimulus brings down the arousal level.*

Quotes from thinking aloud:

" The content of the message matters a lot. If it's a message like "You've done really well." It's difficult to relate it to something negative since it says "really well". "

" Arousal is actually affected by the voice a lot. "

" It's also related to culture. For example, if it's said by a British, it's very very negative. "

" The "I love chocolate " is combined with a cold stimulus. It's still positive but I might think that the chocolate is not that healthy. "

" For the "I tried so hard." with no thermal stimulus, it's difficult to say if it's positive or negative. I think it's neutral in valence but the arousal is not. "

Quotes about wearability:

" If it's something like jewelry, I wouldn't worry about it. But for what it currently looks like, I will be worried about it when hanging outside. "

" I feel that I'm a little bit afraid to move since there are too many wires. "

" The prototype feels strange right now but if it's a jewelry, it should be fine. "

P2

Age: 32

Gender: female

Profession (or current studies): post-doc

Height: 163cm

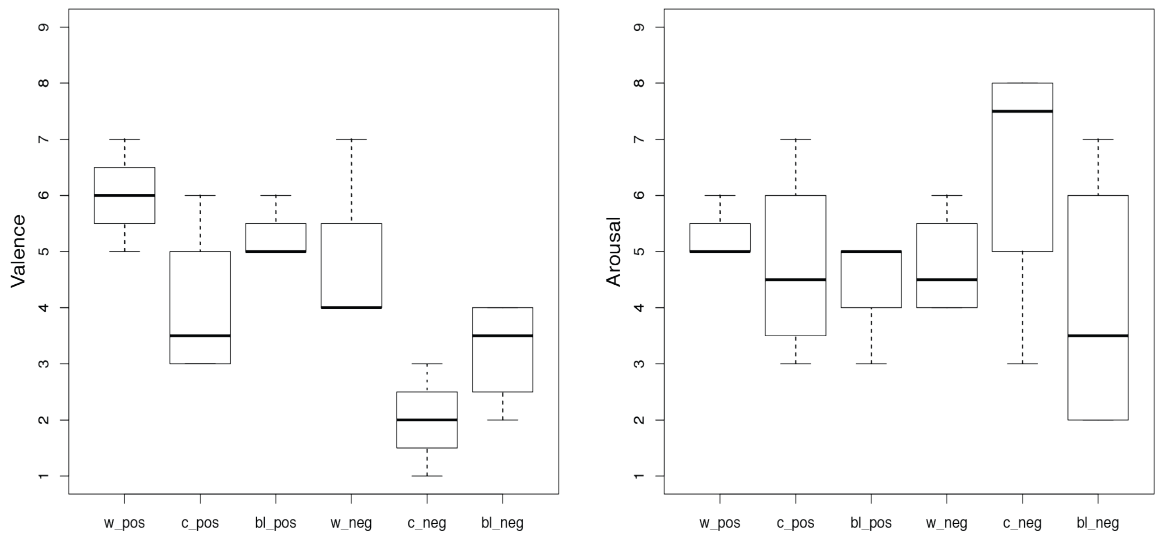
Weight: 59kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Frequently

Room temperature: 22.5°C

Skin temperature: 29.55°C



P2

Quotes from the semi-structured interview:

Warm-positive: If it's a positive message, it increases the positivity of the message.

Warm-negative: I don't know about that one.

Cold-positive: I just don't believe it's a positive message. I felt it more neutral. The cold made it less emotional.

Cold-negative: It makes it more angry or more severe.

Valence and arousal: I think I was focusing more on the valence than i was on the arousal. For positive messages, the arousal is not that affected, maybe a little bit. For the negative message, the cold stimulus made it like high arousal. The warm is harder to tell.

Others: I actually find it really helpful to close my eyes. It makes me focus on it more. what I found most interesting is that by using the heat, I was trying to interpret whether to believe them or not. It's like trying to figure intention, like polygraph.

Quotes from thinking aloud:

" It's interesting. She asks "What do you think you are doing?" but it's warm. It's interesting because it's supposed to be a negative message but with the warm, it makes it feel more neutral. Like he's not mad at this person, he is just asking. I would say it's like slightly negative and arousal is like pretty low. "

" Some messages are easier to convince me. Like someone saying "I love chocolate" is easier to convince me than someone saying "I've tried so hard." In one case, it's like a preference. In one case, it's like your personal effort to do something. "

Quotes about wearability:

" Maybe I feel a little bit tense because people are watching you and they can tell if you are telling truth or not. "

" It makes me look strange. It's probably bad but I'm already a wired person so I don't really mind. "

" It affects my movement a little bit. I probably have to be more careful when I'm drinking coffee. "

P3

Age: 32

Gender: female

Profession (or current studies): DFI

Height: 178cm

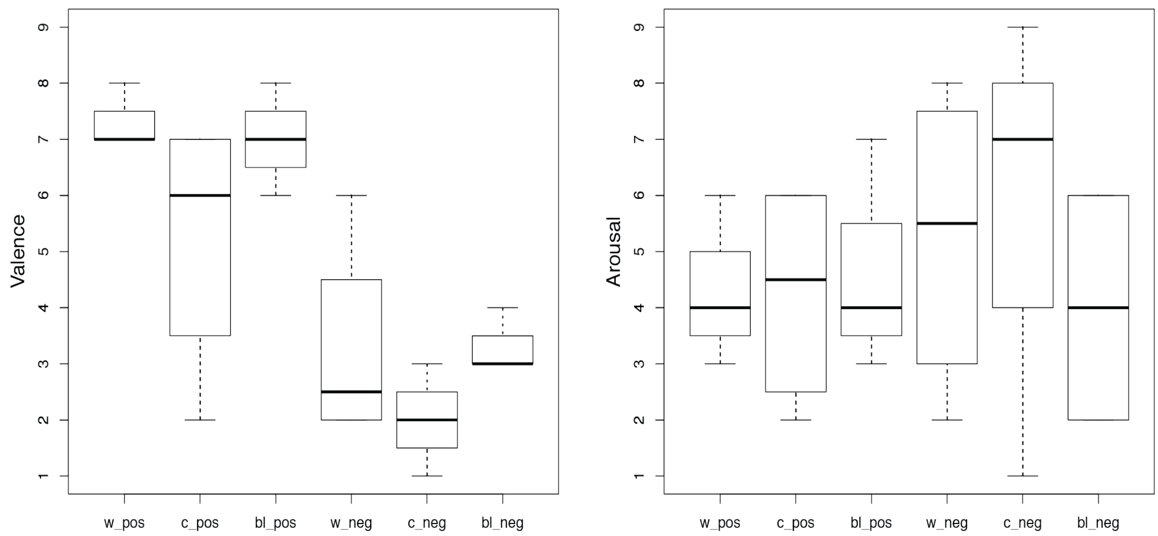
Weight: 60kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Frequently

Room temperature: 22.0°C

Skin temperature: 31.59°C



P3

Quotes from the semi-structured interview:

Warm-positive: If it's warm, I can sense the positive emotion is sincere.

Warm-negative: It's the negative that he's in pain, not depressed.

Cold-positive: I might think if it's ironic.

Cold-negative: I might think he's a little bit excited and depressed.

Valence and arousal: I think the thermal stimulus has more effect on valence. Arousal lies more on the tone. Thermal represents more about the semantic information.

Others: Nothing.

Quotes about wearability:

" The thing is too bulky. And I'm a little bit worried about the wires. "

" It's not attached very tight. "

" The attached part like batteries do have influence on the movement. "

P4

Age: 25

Gender: female

Profession (or current studies): student

Height: 160cm

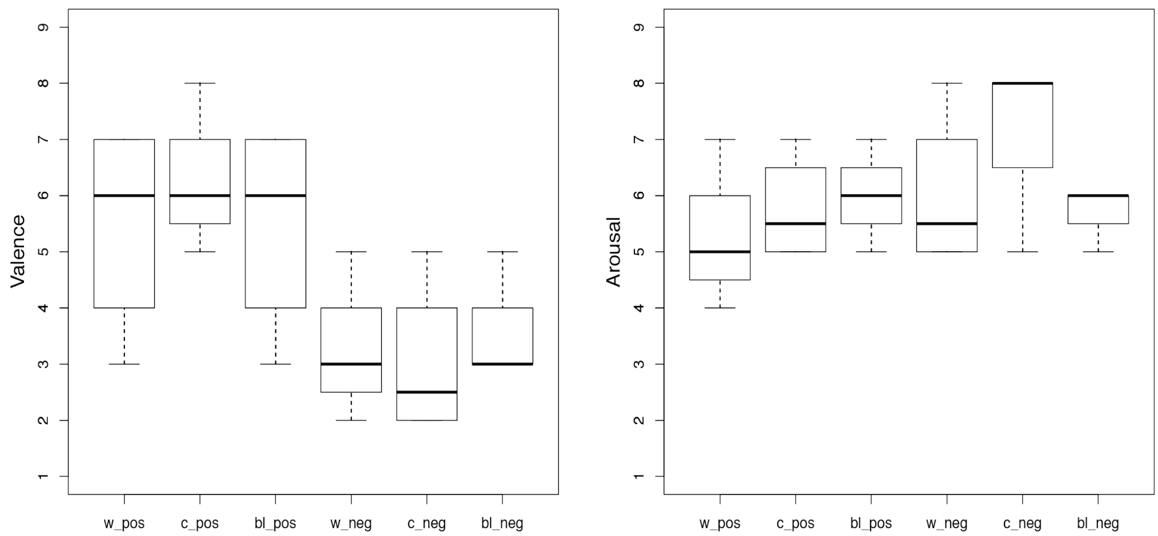
Weight: 48kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Sometimes

Room temperature: 22.6°C

Skin temperature: 29.39°C



P4

Quotes from the semi-structured interview:

Warm-positive: I think the warm is a better match for the positive messages but it shouldn't be warmer than a certain degree. Then it's something negative as well. I don't know if the stimulus is the same but I'm combining the message itself for the feeling.

Warm-negative: I think the higher warmth is better for the negative ones.

Cold-positive: I feel the cold and the positive message is not a good match. If it's not that cold, it's a good match.

Cold-negative: Cold is a better match for the negative ones.

Valence and arousal: Rating arousal is harder than rating valence. Valence is more obvious than arousal. Arousal is highly dependent on that person. Maybe I'm not that affected by that message but someone else might be affected. For example, I might be offended by the messages but I might not be angry. But someone else might be angry.

Others: It's not the direction of the temperature change dominates the valence. How intense the temperature change *determines if it's positive or negative. If the stimulus is too intense, then it's aggressive and enhances the emotion.*

Quotes from thinking aloud:

" So it's cold and it's "It's going to be great". So it's not matching what she says. "

" I like this as well. It's unpleasant and it's cold so it's matching. "

Quotes about wearability:

" It's heavy. It's not harming me but it's not that comfortable of course. "

" I'm anxious because I can't be sure how intense the stimulus will be. "

P5

Age: 24

Gender: female

Profession (or current studies): master from TU Delft

Height: 165cm

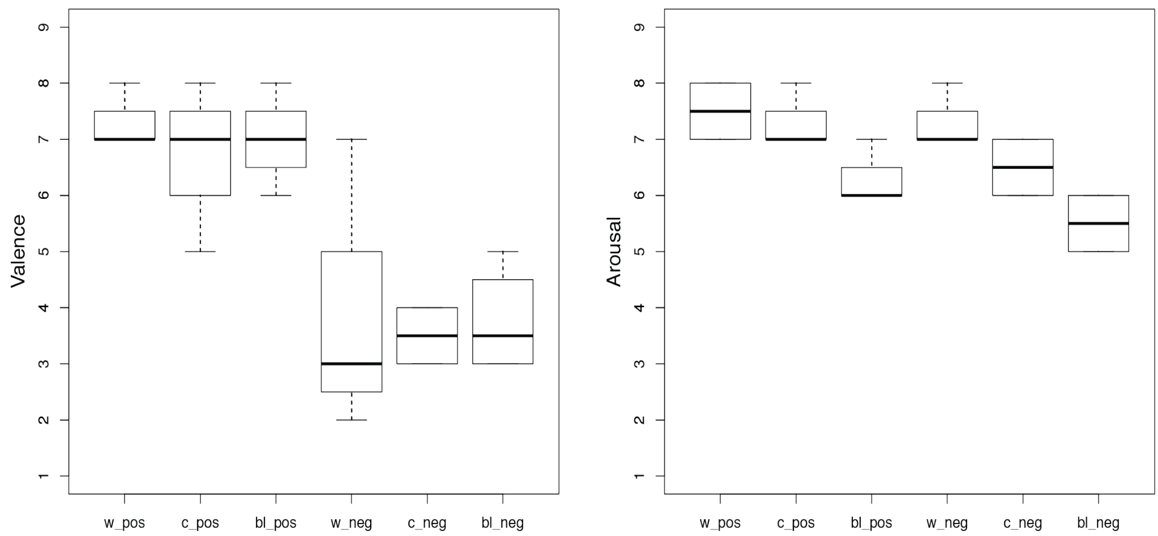
Weight: 47kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Daily

Room temperature: 23.2°C

Skin temperature: 26.89°C



P5

Quotes from the semi-structured interview:

Valence and arousal: The thermal stimulus mainly affect arousal. The effect of warm and cold on arousal has no much difference.

Warm and cold: I won't estimate the valence if I'm sure about if the message is positive or negative already. When I'm not sure about the valence. I will estimate if the message is positive or negative based on the thermal stimulus. And in that case, warm refers to positiveness and cold refers to negativeness.

Others: I think that how intensely the temperature changes dominates the intensity of the emotion.

determines if it's positive or negative. If the stimulus is too intense, then it's aggressive and enhances the emotion.

Quotes from thinking aloud:

" I might still interpret more based on the tone. "

" I think warm is a little bit more positive while cold is more negative. "

" I feel that when the message is confusing, I might use thermal to tell if it's positive or not. "

" The warm feels positive. It's like someone hold you tight and tell you that "You've done really well". "

Quotes about wearability:

" I don't like the device moving but I want to feel the device as long as it's on my body. "

" I'm happy if I have this device on my body. I feel I have something others don't have. It's like I wear a watch on my wrist while others don't. "

" I hope the thing is fixed on my body. "

" I'm a little bit worried about the electric on my body since this is a low fidelity prototype. "

P6

Age: 24

Gender: female

Profession (or current studies): DFI

Height: 169cm

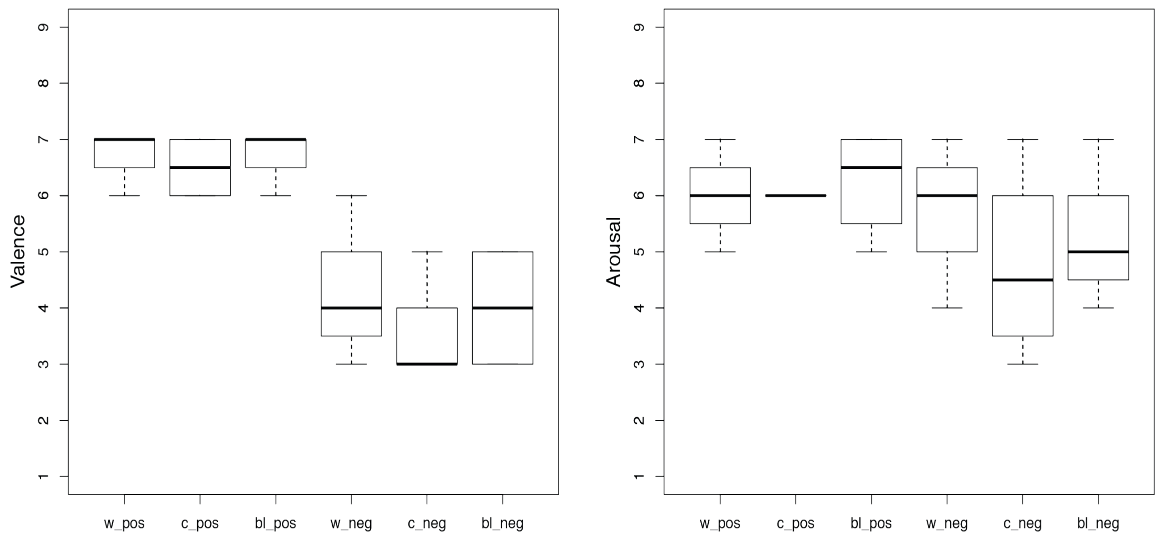
Weight: 58kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Frequently

Room temperature: 22.5°C

Skin temperature: 32.91°C



P6

Quotes from the semi-structured interview:

Warm-positive: It increases the arousal of positive messages.

Warm-negative: It increases the arousal.

Cold-positive: It calms me down.

Cold-negative: It decreases the arousal.

Valence and arousal: In general, it affects arousal. But it might also have some effect on valence. He says that he loves eating chocolate. If there is warm stimulus, I can sense he does love it.

Others: Sometimes I can't sense the stimulus very well.

Quotes from thinking aloud:

" It turns warm and he says "that wasn't very nice of me." It's quite negative. "

" It gets cold and he says "I tried so hard." It's quite unpleasant. "

Quotes about wearability:

" I'm worried about how I look putting this on. It looks not good. "

P7

Age: 32

Gender: male

Profession (or current studies):postdoc

Height: 183cm

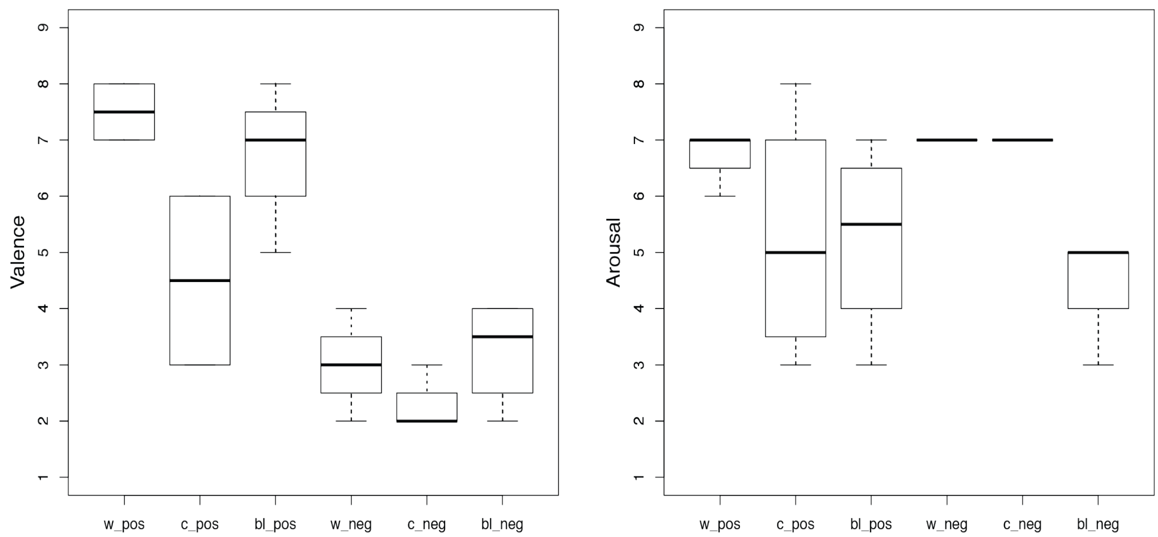
Weight: 93kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Rarely

Room temperature: 23.2°C

Skin temperature: 31.17°C



P7

Quotes from the semi-structured interview:

Warm-positive: The warm stimulus makes it more positive.

Warm-negative: The warm has no effect on negative messages.

Cold-positive: The cold one sometimes makes it not really positive.

Cold-negative: Cold makes it more negative.

Valence and arousal: For warm, it always increases arousal. For cold, it increases arousal if it's a negative message. For positive messages, it decreases the arousal.

Others: Nothing

Quotes from thinking aloud:

" Even though she said it was going to be great, it felt cold. It doesn't feel like great. And also she says in a neutral way. "

" It's truly sorry, truly sad (with the cold). "

Quotes about wearability:

" I'm not worried about how I look but you have all these things on your chest and the T-shirt is really tight. "

P8

Age: 25

Gender: male

Profession (or current studies): student. IPD

Height: 178cm

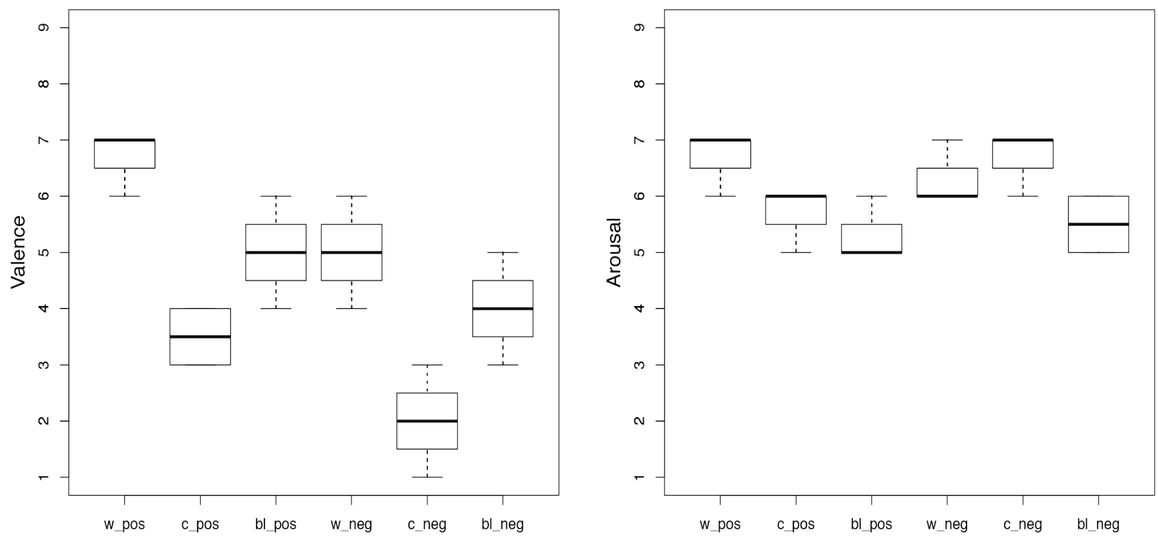
Weight: 80kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Daily

Room temperature: 23.5°C

Skin temperature: 32.47°C



P8

Quotes from the semi-structured interview:

Warm-positive: It brings more positive feelings.

Warm-negative: He is saying something bad, but with a good intention, like parents.

Cold-positive: He is not speaking sincerely.

Cold-negative: It's rigorous and the intention is not good, unfriendly.

Valence and arousal: For valence, warm brings it up while cold brings it down. For arousal, thermal stimulus always brings it up.

Others: Cold is more intense because I'm more sensitive to cold.

Quotes from thinking aloud:

" Heating does make the messages more positive. "

" The cold makes what he said sounds insincerely. "

" It feels depressed with the cold. "

" I feel the cold do affects my emotion. I remember I heard this message before and it sounds positive. But this time it gets cold and it feels like he is trying to be strong in adversity. "

Quotes about wearability:

" This thing is pretty tiny so I think it can be covered by clothes. I won't be embarrassed wearing it. "

" I'm a little bit worried about the attachment when I'm moving. "

" I'm a little bit worried about if it might harm me when I fall down since it's so hard. "

P9

Age: 25

Gender: male

Profession (or current studies): student

Height: 173cm

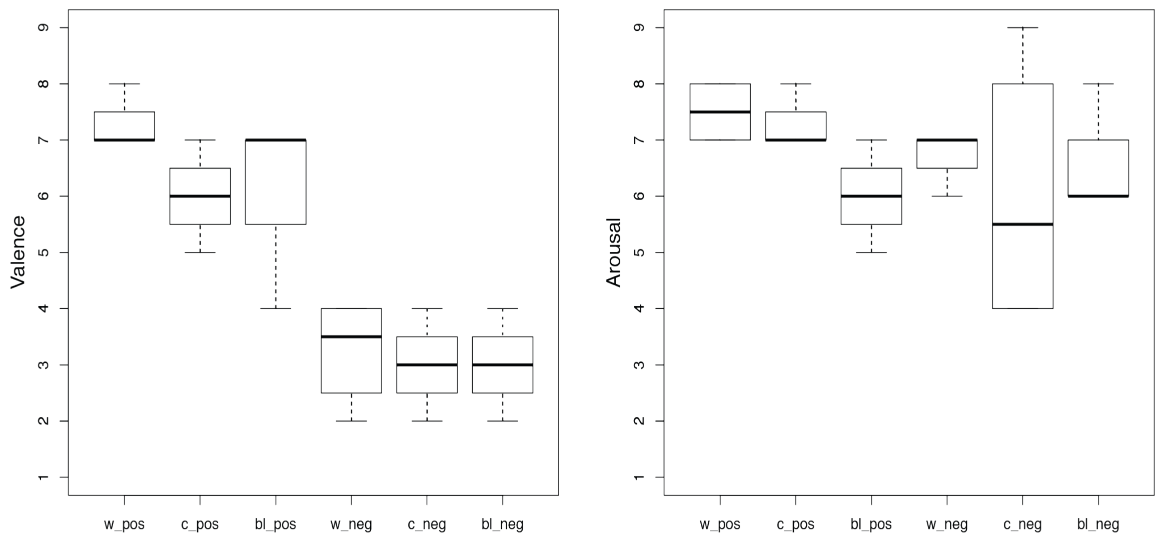
Weight: 63kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Sometimes

Room temperature: 22.5°C

Skin temperature: 30.51°C



P9

Quotes from the semi-structured interview:

Warm-positive: Warm match positive

Warm-negative: If it's too intense.

Cold-positive: Cold matchs negative

Cold-negative: If it's too intense.

Valence and arousal: Both increases arousal but cold sometimes feels not intense then there is no clear effect.

Others: I would appraise my rating by combining the voice and the thermal stimulus.

Quotes from thinking aloud:

" I don't think she likes chocolate (with the cold). "

Quotes about wearability:

" The clothes is little bit tight. "

" The clothes is not very comfortable. "

P10

Age: 25

Gender: male

Profession (or current studies): student

Height: 170cm

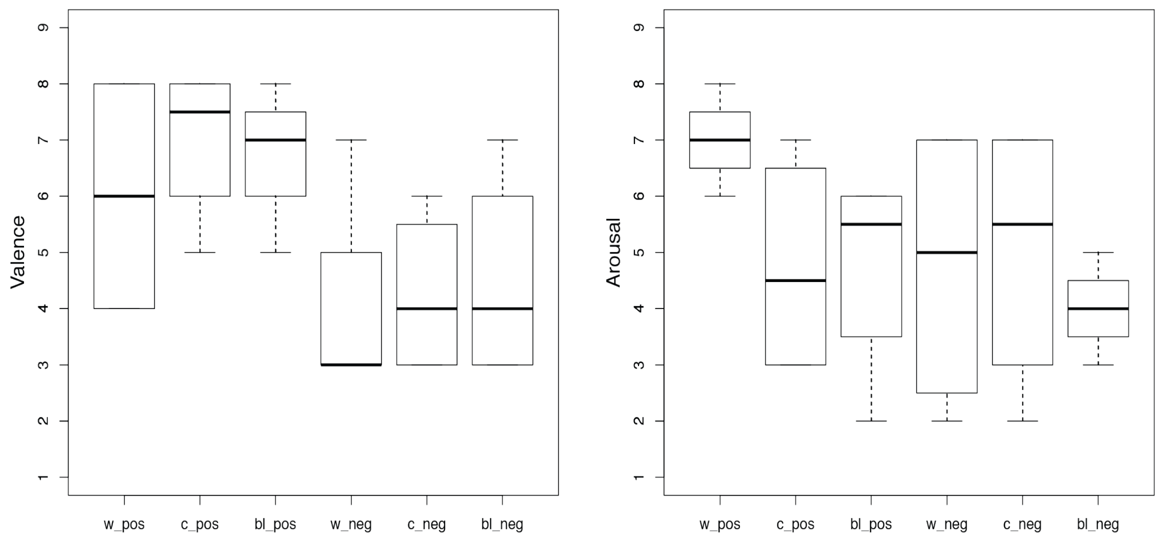
Weight: 62kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Rarely

Room temperature: 22.5°C

Skin temperature: 30.37°C



P10

Quotes from the semi-structured interview:

Warm-positive: If it's very warm, it contributes to positive.

Warm-negative: If it's not very warm, I don't like the feeling and it brings the emotion to negative. But if it's very warm, it's makes it feel less negative.

Cold-positive: Cold makes me feel it's more positive.

Cold-negative: Cold makes me feel it's more positive.

Valence and arousal: I feel warm increases arousal while cold doesn't affect arousal.

Others: I like cold stimulus. It feels comfortable and it has less effect on emotion perception.

Quotes about wearability:

" I’m not worried about wearing these kinds of things. "

" It will affect me a lot when I’m doing sports. "

" I’m not worried about the thermal stimulus but I’m concerned about the electrical part like batteries. "

P11

Age: 24

Gender: male

Profession (or current studies): MSc Information Systems

Height: 190cm

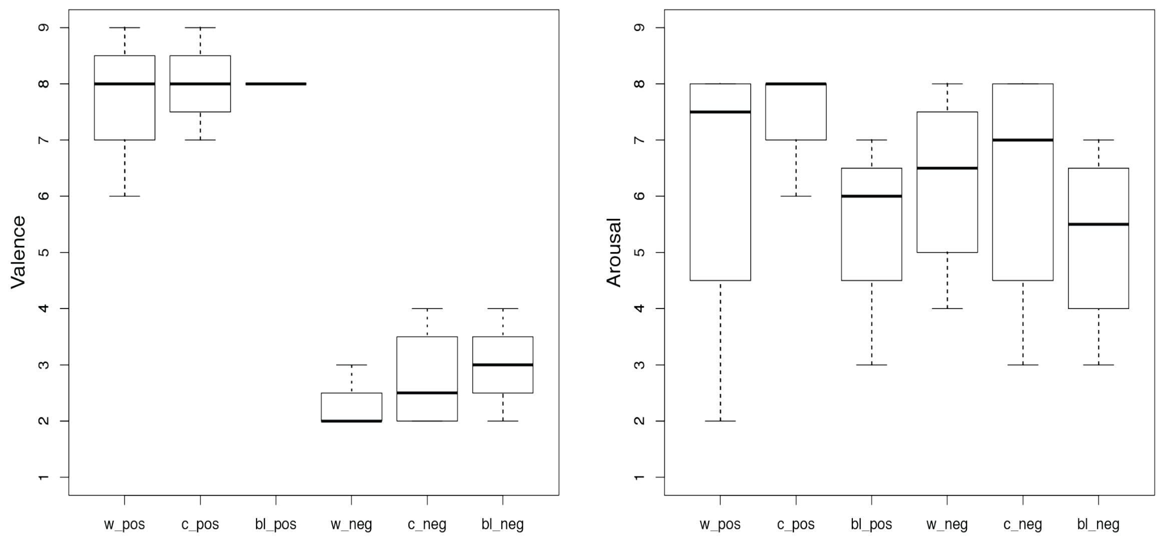
Weight: 80kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Daily

Room temperature: 22.5°C

Skin temperature: 30.09°C



P11

Quotes from the semi-structured interview:

Warm-positive: Increase arousal.

Warm-negative: Increase arousal.

Cold-positive: Increase arousal.

Cold-negative: Increase arousal.

Valence and arousal: I think the high temperature change adds dimension to the arousal. Valence you get it mostly from the tone. But the communication for arousal, you definitely adds a different dimension.

Others: I think it's a little bit localised but for the full emotion I think it's bigger, then you have a bigger effect.

Again, I think it's the difference that communicates if it's excited rather than if it's hot or cold. I think if it's a full body experience like you can get the chills when somebody saying something sad maybe, but in such a local place, it doesn't have difference.

The voice is still the main indication of the valence.

I think the spot is good. I feel the scale is too big.

I think people do feel warm when they feel emotions. But people are not always aware of it. So it's interesting to do the reverse.

Quotes from thinking aloud:

" He loves chocolate. It was quite cold. It's a big temperature change so I would go with quite excited. "

Quotes about wearability:

" I can imagine that if it's designed well, it won't look wired. "

" All the circuit, if I'm going in the rain then I don't feel secure. "

P12

Age: 25

Gender: male

Profession (or current studies): student Parallel & Distributed Computer Systems

Height: 178cm

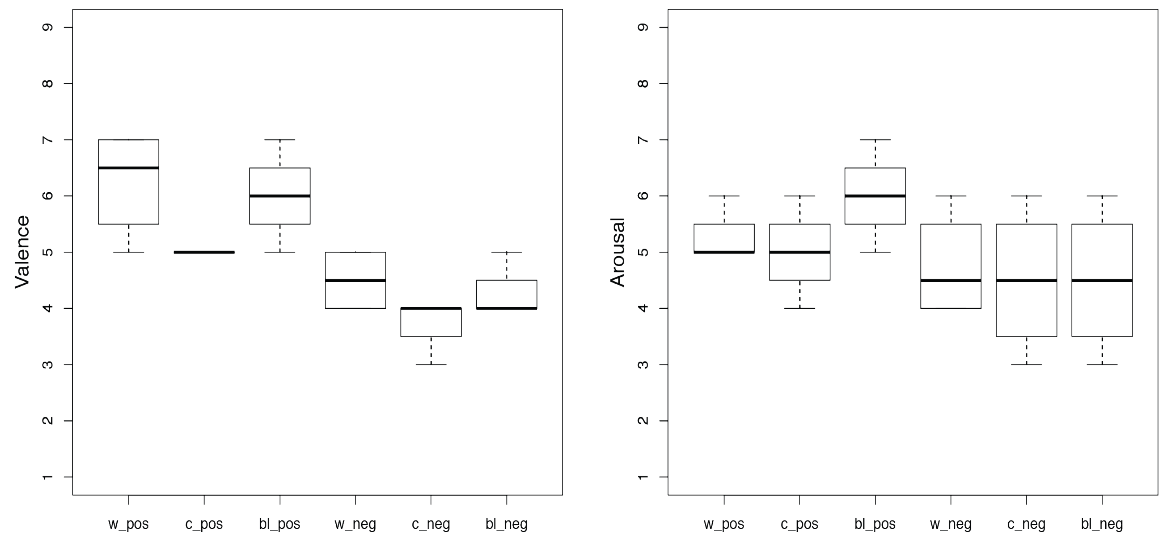
Weight: 75kg

How often do you use voice messages to communicate with friends/family (e.g., WhatsApp, FB Messenger or WeChat)?

Rarely

Room temperature: 23.0°C

Skin temperature: 32.95°C



P12

Quotes from thinking aloud:

" This time it was a little bit cold and he said "It wasn't very nice". It was sad. It was calm and slow as well."

"It was cool and he said "It was great". He sounds a little bit excited I guess, not that much."

"That was 't very nice of me. This time it was warm. But he still sound bad. He's still calm."

Quotes about wearability:

" Wearing this outside, I wouldn't be like extremely worried but I would be like, hey, this looks kind of wired. "

" All the circuit, if I'm going in the rain then I don't feel secure. "

Appendix 9

Valence and arousal analysis per sentence

Apart from the new plots, the ratings per sentence are also generated to find out how different sentences affect the distribution of the ratings.

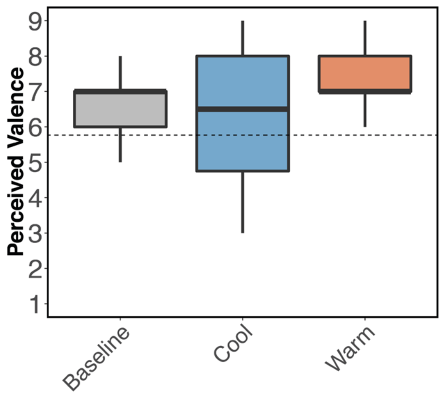
In summary, emotion perception from voice message with thermal stimulus is a very subjective process. There exists no strict mappings between the thermal stimulus and valence or arousal change. For valence, warm stimulus tends to bring the neutrally spoken positive message perceived back to normal. Cold stimulus has the same effect on negative messages. As for arousal, the heat helps people to better understand the emotional state of a person if he or she speaks neutrally. However, the effect on the positive messages is more obvious than that on negative ones. The cold stimulus only helps for negative messages.

The detailed interpretation per sentence is described in this section.

Valence analysis per sentence

Positive message one

It's going to be great.



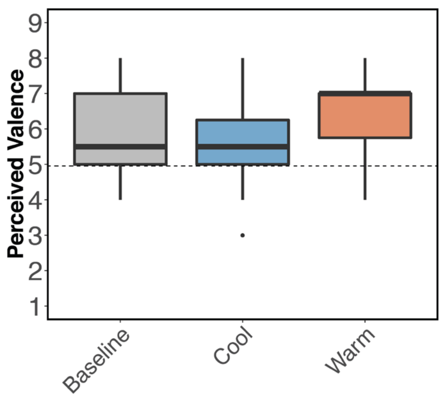
Positive Message 1_valence

Compared to baseline	Warm	Cool
Increase	*7 participants* P1, P2, P5, P8, P9, P10, P11	*4* P1, P5, P10, P11
Decrease	*1* P3	*7* P2, P3, P4, P7, P8, P9, P12
No change	*4* P4, P6, P7, P12	*1* P6

Participants are quite consistent about the valence. People in general think that it's slightly positive. When the warm stimulus is added, most people (seven participants, P1, P2, P5, P8, P9, P10, P11) feel it's more positive. Four people (P4, P6, P7, P12) think the thermal stimulus has no effect. One participant (P3) thinks that it decreases the arousal. Cold stimulus widens the ratings in both directions, seven people (P1, P2, P5, P8, P9, P10, P11) think the cold reinforces the positive feelings while four people (P4, P6, P7, P12) think that it weakens the positivity. In general, the ratings on this message agree with the overall trend.

Positive message two

Hmm, I love chocolate.



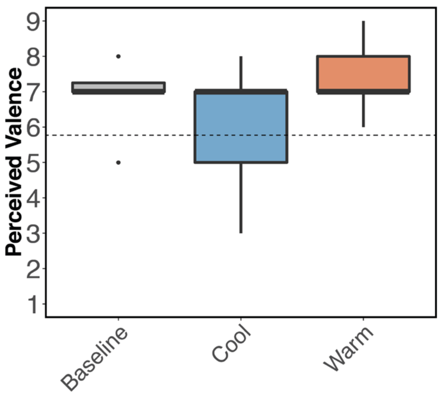
Positive Message 2_valence

Compared to baseline	Warm	Cool
Increase	*4 participants* P6, P7, P8, P9	*4* P7, P8, P9, P10
Decrease	*2* P10, P11	*2* P1, P3
No change	*6* P1, P2, P3, P4, P5	*6* P2, P4, P5, P6, P11, P12

People think it's neutral or slightly positive but with a wide distribution. When the warm stimulus is added, the perceived valence is increased. Four person (P6, P7, P8, P9) think that warm stimulus increases valence while six participants (P1, P2, P3, P4, P5) feel that there is no change. The other two (P10, P11) think that valence is decreased. Most people (P2, P4, P5, P6, P11, P12) don't think the cold stimulus affects the valence for this message while four participants think it increases valence. Two person think the cold stimulus decreases valence. Again, the ratings of positive messages contribute to the overall trend with a higher proportion on no change. The ratings of cold stimulus is very different from others, which explains why there is no agreement on cold stimulus' effect.

Positive message three

You've done really well.



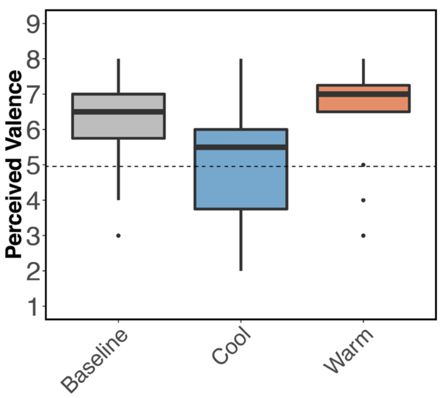
Positive Message 3_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P1, P2, P3, P7, P8	*1* P4
Decrease	*3* P5, P6,P10	*6* P2, P5, P7, P8, P11, P12
No change	*4* P4, P9, P11, P12	*5* P1, P3, P6, P9, P10

People are quite consistent about the valence and think it's slightly positive. The warm stimulus increases the valence for five people (P1, P2, P3, P7, P8). Four participants (P4, P9, P11, P12) feel that the thermal stimulus doesn't affect valence while others (P5, P6, P10) think it decreases valence. The cold stimulus brings the compliment back to neutral for most people (P2, P3, P6, P9, P10). Five participants (P2, P5, P7, P8, P11, P12) feel that there is no change while one person (P4) think that it increases valence. The impact of warm stimulus on message three is similar to that on message two. When it comes to the cold, the impact is more consistent in terms of the changing direction of valence. However, it disagrees with the pattern of message one and two.

Positive message four

I knew I could do it.



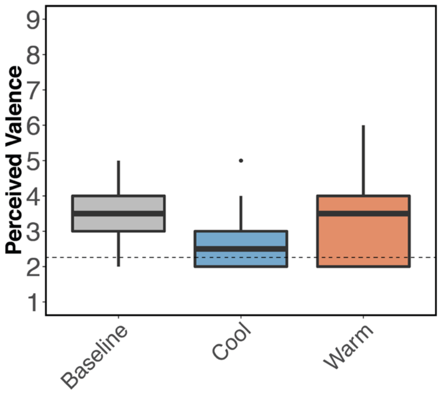
Positive Message 4_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P1, P3, P5, P8, P12	*2* P4, P10
Decrease	*1* P10	*9* P1, P2, P3, P5, P6, P7, P8, P9, P12
No change	*6* P2, P4, P6, P7, P9, P11	*1* P11

It is perceived as neutral or slightly positive. Warm stimulus increases valence for a few people. Five person (P1, P3, P5, P8, P12) think that the warm stimulus increases the valence while six people (P2, P4, P6, P7, P9, P11) feel that there is no effect. The ratings with cold stimulus are decreased to neutral or even decreased to negative. Nine people report that valence is decreased. Some participants said that they can't tell if this one is positive or not according to the content itself. Therefore, they turn to the thermal for detection and regard the cold as negative. Therefore, the result of this message only contributes to the pattern for warm stimulus.

Negative message one

What do you think you are doing?



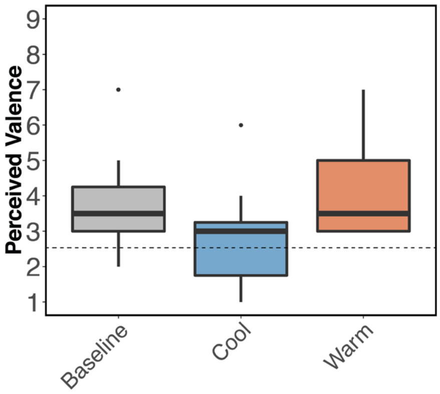
Negative Message 1_valence

Compared to baseline	Warm	Cool
Increase	*3 participants* P1, P6, P8	*0*
Decrease	*3* P3, P5, P11	*8* P1, P2, P3, P4, P5, P7, P8, P11
No change	*6* P2, P4, P7, P9, P10, P12	*4* P6, P9, P10, P12

Participants are quite consistent about the negative valence. When the warm stimulus is added, the range is broaden. Six participants (P2, P4, P7, P9, P10, P12) think that there is no change while three participants (P1, P6, P8) feel that the warm stimulus increases valence. People are quite consistent about the effect of cold stimulus. Most people (P1, P2, P3, P4, P5, P7, P8, P1) think that the cold stimulus makes the message perceived more negative while four person (P6, P9, P10, P12) think there is no change. Therefore, the effect of cold stimulus agrees with the global trend but the ratings for warm stimulus doesn't agree with the trend by laying a higher weight on no change.

Negative message two

Ugh...Cover your mouth when you sneeze.



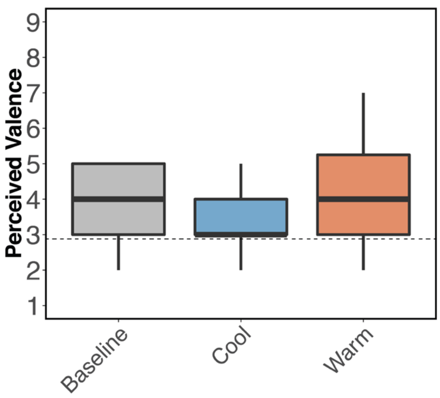
Negative Message 2_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P2, P3, P9, P11, P12	*2* P9, P11
Decrease	*2* P5, P7	*7* P1, P2, P3, P5, P7, P8, P10
No change	*5* P1, P4, P6, P8, P10	*3* P4, P6, P12

People think it's more or less negative but with a wider distribution. With the warm stimulus, the distribution gets wider while five people (P2, P3, P9, P11, P12) think it's less negative. Another five participants (P1, P4, P6, P8, P10) think that it doesn't affect valence while two person (P5, P7) think that it makes the message more negative. As for cold stimulus, most participants (P1, P2, P3, P5, P8, P10) think that it decreases valence while three people (P4, P5, P12) feel that there is no change. Two people (P9, P11) think that the cold stimulus makes it less negative. The ratings for cold stimulus contributes to the overall trend while the ratings of the effect from heat varies by having a higher proportion on both increasing and no change.

Negative message three

I tried so hard.



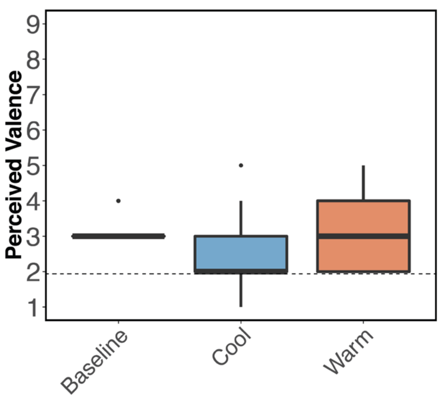
Negative Message 3_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P1, P2, P5, P7, P9	*1* P5
Decrease	*4* P6, P10, P11, P12	*6* P1, P2, P6, P8, P10, P12
No change	*3* P3, P4, P8	*5* P3, P4, P7, P9, P11

In terms of message three, people also think it's more or less negative with a wide distribution. The warm stimulus has effects on both directions. Five people (P1, P2, P5, P7, P9) think that the stimulus increases valence while four person (P6, P10, P11, P12) feel the opposite way. As for the cold stimulus, the changing direction is quite consistent. Only one person (P5) feel that the stimulus increases valence. Six participants (P1, P2, P6, P8, P10, P12) think the cold stimulus decreases valence while five person (P3, P4, P7, P9, P11) think that there is no effect. This message makes the pattern variable by putting a higher weight on both increasing and decreasing. of the changing direction of valence. However, it disagrees with the pattern of message one and two.

Negative message four

That wasn't very nice of me.



Negative Message 4_valence

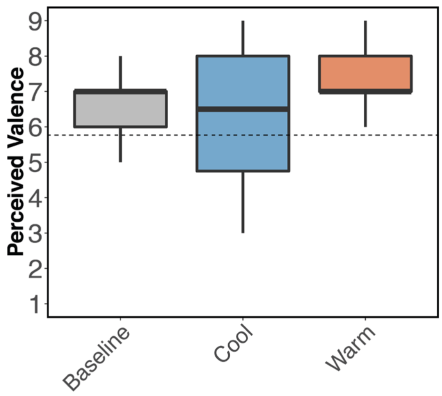
Compared to baseline	Warm	Cool
Increase	*4 participants* P2, P6, P8, P12	*2* P5, P10
Decrease	*5* P3, P4, P7, P9, P11	*9* P1, P2, P3, P4, P7, P8, P9, P11, P12
No change	*3* P1, P5, P10	*1* P6

For message four, people are very consistent about the valence. Most people think it's quite negative. Adding a warm stimulus also widens the distribution without an agreed changing direction in terms of valence. Four participants (P6, P10, P11, P12) think it increases valence while five people (P1, P2, P5, P7, P9) feel it makes the stimulus more negative. Three participants (P1, P5, P10) think the warm stimulus has no effect on valence. As for the cold stimulus, most people (P1, P2, P3, P4, P7, P8, P9, P11, P12) think that it makes the message perceived more negative while two person (P5, P10) think it brings the message back to neutral. Participant six thinks that there is no change. The distribution of ratings on this message is quite similar to the third one, which also brings the similar effect on the overall trend.

Arousal analysis per sentence

Positive message one

It's going to be great.



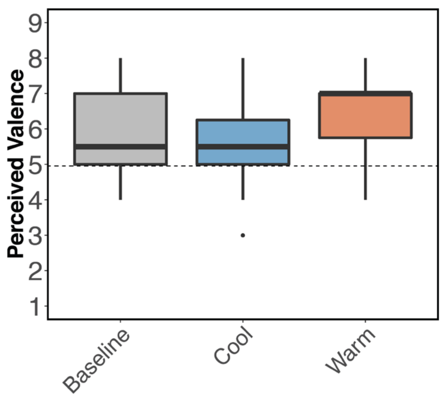
Positive Message 1_valence

Compared to baseline	Warm	Cool
Increase	*7 participants* P1, P2, P5, P8, P9, P10, P11	*4* P1, P5, P10, P11
Decrease	*1* P3	*7* P2, P3, P4, P7, P8, P9, P12
No change	*4* P4, P6, P7, P12	*1* P6

Message one is in general perceived from calm to neutral without thermal stimulus. Most participants (P1, P2, P3, P7, P8, P9, P10, P11) feel that warm stimulus increases arousal. Three participants (P4, P6, P12) think that warm decreases arousal while one person (P5) feel that there's no change. As for the cold stimulus, the result is quite diverse. Five people (P3, P5, P7, P9, P11) think that cold stimulus increases arousal while four person (P1, P2, P4, P6) feel the opposite way. The other three (P8, P10, P12) feel no change. This message contributes to the overall trend for warm stimulus. For the cold stimulus, the ratings on the three options are more or less the same.

Positive message two

Hmm, I love chocolate.



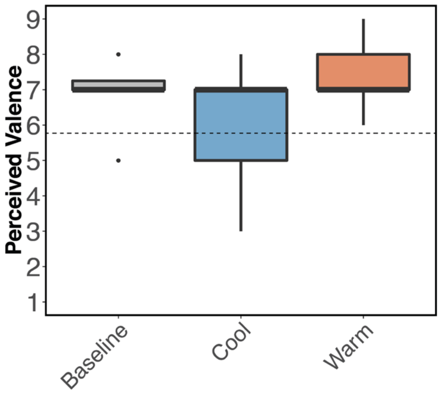
Positive Message 2_valence

Compared to baseline	Warm	Cool
Increase	*4 participants* P6, P7, P8, P9	*4* P7, P8, P9, P10
Decrease	*2* P10, P11	*2* P1, P3
No change	*6* P1, P2, P3, P4, P5	*6* P2, P4, P5, P6, P11, P12

For message two, there is no clear trend for warm stimulus. Five participants (P5, P7, P8, P9, P10) think that the warm stimulus increases arousal while four person (P1, P2, P4, P6) feel that there is no change. Three people think the heat brings down arousal. For the cold stimulus, people can't reach an agreement on how arousal is affected. Seven people (P5, P6, P7, P8, P9, P10, P11) feel that it increases arousal while four people (P1, P2, P3, P12) feel that it has decreasing effect. Participant four feels that there is no change.

Positive message three

You've done really well.



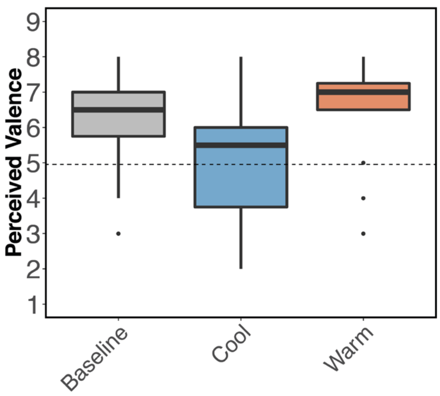
Positive Message 3_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P1, P2, P3, P7, P8	*1* P4
Decrease	*3* P5, P6,P10	*6* P2, P5, P7, P8, P11, P12
No change	*4* P4, P9, P11, P12	*5* P1, P3, P6, P9, P10

The warm stimulus increases arousal for most people (P1, P2, P5, P7, P8, P9, P10). Three person (P3, P11, P12) think that the warm stimulus has no effect while the other two feel that it decreases arousal. As for the cold stimulus, most people think that it decreases arousal (P1, P3, P6, P7, P10, P11) or has no effect (P4, P8, P12). Three person think that the cold stimulus increases the excitement.

Positive message four

I knew I could do it.



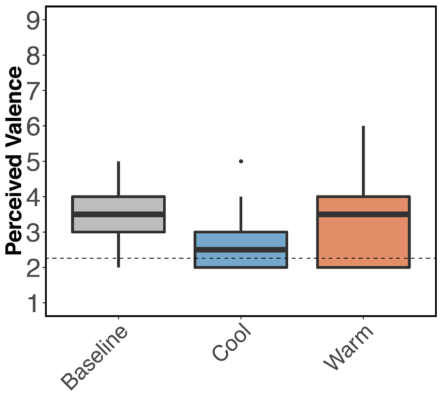
Positive Message 4_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P1, P3, P5, P8, P12	*2* P4, P10
Decrease	*1* P10	*9* P1, P2, P3, P5, P6, P7, P8, P9, P12
No change	*6* P2, P4, P6, P7, P9, P11	*1* P11

For message four, the warm stimulus in general increases arousal. Six people (P5, P6, P8, P9, P10, P11) feel that arousal is increased while four person (P1, P2, P4, P7) think there is no change. Two people feel arousal is decreased with the warm stimulus. The cold stimulus widens the rating distribution. Five people (P3, P5, P8, P10, P11) think that it increases arousal while three people (P1, P7, P12) feel arousal is decreased. Four participants (P2, P4, P6, P9) think that there is no change.

Negative message one

What do you think you are doing?



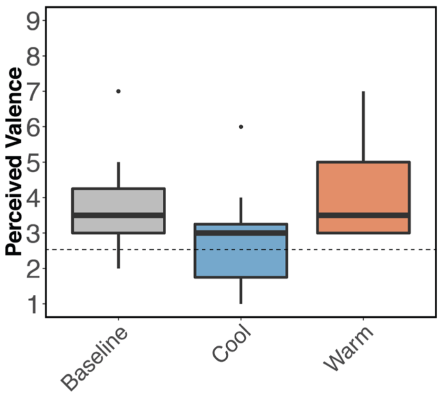
Negative Message 1_valence

Compared to baseline	Warm	Cool
Increase	*3 participants* P1, P6, P8	*0*
Decrease	*3* P3, P5, P11	*8* P1, P2, P3, P4, P5, P7, P8, P11
No change	*6* P2, P4, P7, P9, P10, P12	*4* P6, P9, P10, P12

For message one, warm stimulus doesn't have a global effect on arousal. Six participants (P1, P3, P5, P6, P7, P10) think that it increases arousal while four person (P2, P4, P9, P11) feel that the message feels more calm. Two person (P8, P12) think that there is no change. As for the cold stimulus, most people feel that arousal is increased. Only participant six and twelve feel no effect.

Negative message two

Ugh...Cover your mouth when you sneeze.



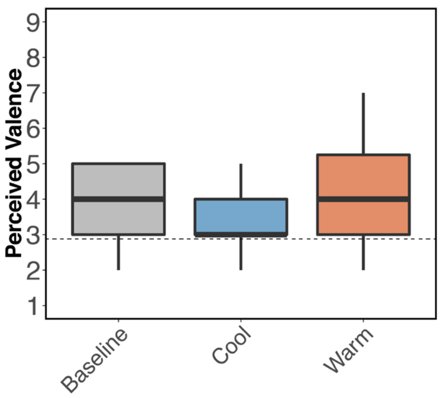
Negative Message 2_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P2, P3, P9, P11, P12	*2* P9, P11
Decrease	*2* P5, P7	*7* P1, P2, P3, P5, P7, P8, P10
No change	*5* P1, P4, P6, P8, P10	*3* P4, P6, P12

For message two, most participants (P1, P3, P5, P7, P8, P9, P12) think the warm stimulus increases arousal while three person (P2, P10, P11) feel the message feels more calm. Two person (P4, P6) think that there is no change. As for the cold stimulus, most people feel that arousal is increased. Only participant six feels no change while participant nine thinks that arousal is decreased.

Negative message three

I tried so hard.



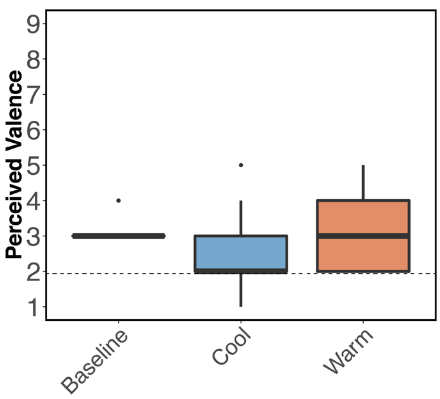
Negative Message 3_valence

Compared to baseline	Warm	Cool
Increase	*5 participants* P1, P2, P5, P7, P9	*1* P5
Decrease	*4* P6, P10, P11, P12	*6* P1, P2, P6, P8, P10, P12
No change	*3* P3, P4, P8	*5* P3, P4, P7, P9, P11

For message three, the majority (P1, P2, P5, P7, P9, P11) still think the warm stimulus increases arousal while three person (P3, P10, P12) think the message feels more calm. The rest three (P4, P6, P8) don't feel the effect of warm stimulus. As for the cold stimulus, most people (P2, P3, P5, P7, P8, P9, P10) feel that arousal is increased. Three person (P1, P4, P6) feel that there is no change while two participants (P11, P12) think arousal is decreased.

Negative message four

That wasn't very nice of me.



Negative Message 4_valence

Compared to baseline	Warm	Cool
Increase	*4 participants* P2, P6, P8, P12	*2* P5, P10
Decrease	*5* P3, P4, P7, P9, P11	*9* P1, P2, P3, P4, P7, P8, P9, P11, P12
No change	*3* P1, P5, P10	*1* P6

As for message four, people are quite consistent about the warm stimulus' effect on arousal. Most people think the heat increases the perceived excitement while two person (P3, P9) feel no change. For the cold stimulus, six people (P2, P4, P7, P8, P11, P12) feel that arousal is increased while four person (P3, P6, P9, P10) feel the opposite. Two person (P1, P5) feel that there is no change.