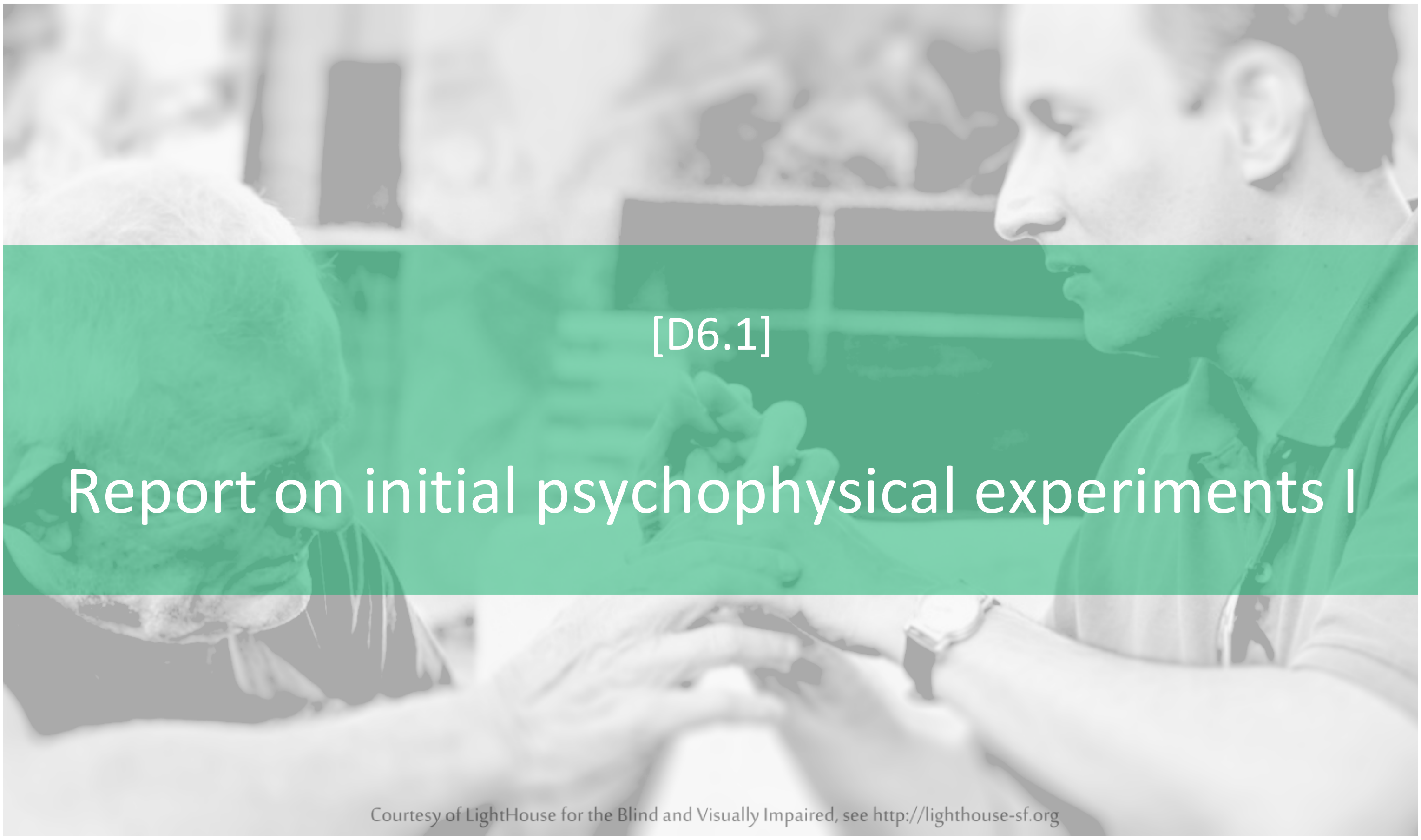
SUITCEYES

1 Jan 2018 - 31 Dec 2020

Smart, User-friendly, Interactive, Tactual, Cognition-Enhancer, Yielding Extended Sensosphere
Appropriating sensor technologies, machine learning, gamification and smart haptic interfaces



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Report on initial psychophysical experiments I

Courtesy of LightHouse for the Blind and Visually Impaired, see http://lighthouse-sf.org

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Dissemination level		
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Glossary	
Abbr./ Acronym	Meaning

Contents

Abstract

A series of experiments was performed with combined equipment from the University of Leeds, the University of Borås and the Vrije Universiteit (VU) Amsterdam. The overall goal was to test the suitability of thermal stimulation for implementation in a HIPI (Haptic Intelligent Personalised Interface). In addition, a literature search was made to provide an overview of current developments of thermal stimulation at body sites other than the hand or face.

The literature review showed that interest in thermal stimulation is increasing, but mostly focused on thermal displays to be touched by the hand. Only a limited number of studies goes beyond tablet-like displays. Therefore, investigating thermal stimulation at other body sites is of interest both from a fundamental point of view and for potential application in a HIPI.

The experiments showed that the addition of a heat sink will be essential in order to make sure that the temperature more quickly returns to baseline. In addition, such a heat sink will also create the possibility to use cooling stimuli, which according to the literature are often more salient than warming stimuli. Results also showed that participants were able to detect thermal stimulation on forearm or upper arm, but it required quite some concentration, even if the stimuli were presented on different arms. This had probably also to do with the overall temperature rise over trials. Finally, it was remarked by all participants that it felt as if the skin temperature between two distinct sites of stimulation also rose. However, control measurements showed clearly that the temperature in between sites remained constant. This seems an interesting perceptual phenomenon that will be investigated in the near future.

1 Introduction

The work done for this Workpackage 6 will be in close collaboration and interaction with, in particular, Workpackages 4 and 5. One of the main goals of Workpackage 6 is to explore new ideas about how information could be conveyed by means other than visual or auditory stimulation. Of particular interest are haptic stimulations in many varieties, such as vibrations and thermal signals. The present study investigated the potential usability of thermal stimulation for implementation in a HIPI (Haptic Intelligent Personalised Interface), both by a study of the recent literature and a pilot experiment with a set-up composed of components of three participating partners.

For the present intended purposes of the HIPI, thermal displays for the hand or fingers are less useful and will not be considered as we want the hands to be free for use in other or additional tasks. For obvious reasons, also thermal stimulation of the face will not be considered, even though the face is very sensitive. Based on the experimental findings of Stevens and Choo (1998), we decided to focus our first experiments on thermal stimulation of the forearms and upper arms, as these body sites were about as sensitive as areas on the hand and potentially suitable for stimulation by a HIPI.

In the next sections, we will first present an overview of relevant literature. Next, we describe our set-up, the methods, and the experimental results, followed by some discussion and conclusions.

2 Overview of recent relevant studies

Compared to vibrotactile stimulation, there are much less studies investigating sensitivity to thermal stimulation. The majority of these thermal studies investigated thermal detection by the hand or fingers (e.g. Bergmann Tiest and Kappers, 2009; Green, 1977; Nilsson and Lundström, 2001; Nilsson et al., 2008; Sato and Maeno, 2012; Wilson et al., 2012). Nice overviews are presented by Jones and Ho (2008) and Jones (2009). Stevens and Choo (1998) investigated thermal detection thresholds for both warming and cooling stimuli on several places on the body and they found a very strong body site dependency. The face (lips, cheeks and forehead) was most sensitive to thermal stimulation, the lower extremities (toe, sole and calf) were the least sensitive. The difference in sensitivity was about a factor 100 and thus very substantial. The upper limbs and the torso had intermediate sensitivities. All body parts were more sensitive to cooling than to warming. Detection performance declined with age. Gray et al. (1982) also reported that participants, both children and adults, and both male and female, had lower thresholds for cooling (-0.15°C) than for warming stimuli (+1.04°C) when tested on the volar site of the forearm.

There have been a few studies investigating the usefulness and feasibilty of thermal stimulation of body parts other than the hand or face. Wilson et al. (2011) studied thermal detection at body sites where typically a mobile phone is located, like the fingers, the thenar, the forearm and the upper arm. They found that the intensity of the stimulus, that is the rise or fall of temperature with respect to baseline, influences detection: higher intensities result in better detection and faster response times. Cooling is detected faster than warming. A higher rate of change improves detection, but reduces comfort. Thresholds for the different body sites were as follows: thenar (1.9°C), forearm (2.2°C), upper arm (2.3°C) and finger (2.9°C). Similar tests in an indoor mobile setting (as opposed to a static situation) showed that performance dropped significantly, although most of the observed patterns and dependencies remained. The same group also investigated the influence of placing a textile between the skin and the thermal stimulus (Halvey et al., 2011). They placed the stimulus either directly on the skin or on a piece of cotton or nylon on the thenar, the thigh or the waist. Also in these experiments, higher intensity and faster rate of change improved performance. Detection percentage depended strongly on material, namely 65%, 47%, and 36% for none, nylon and cotton, respectively. This indicates that materials with lower thermal conductivity require a higher intensity. However, users rated comfort higher when the stimulation was provided via a textile.

Experiments with a quite different focus were done by Bolton and colleagues (2015) who tested a device worn around the wrist capable of gracefully interupting attention of the user. They found, similar to the previously mentioned studies, that intensity and rate of change both influence detection and that cooling has a stronger effect than warming. Lee and Lim (2010) show in a very informal and preliminary experiment the potential of thermal messaging in interpersonal communication. Finally, Gooch and Watts (2010) tested a 'thermal harness' through which a thermal hug could be given as a form of social interaction from one person to another. Most of their outcome measures did not give any significant result, although a questionnaire showed that a thermal hug increased feelings of social presence between participants.

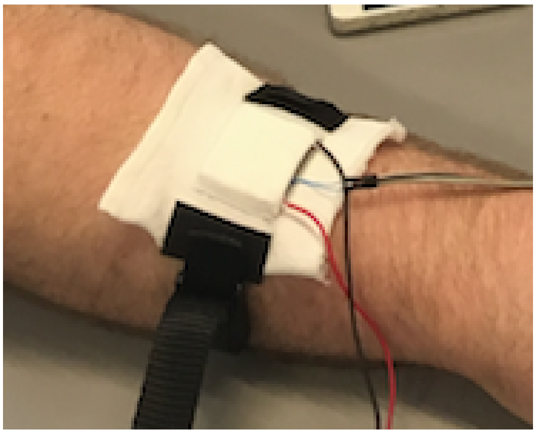


Figure 1: Peltier element in knitted pocket strapped to the skin of the forearm. The Peltier element is concealed by the fabric but is contacted by a red and a black wire. A thermistor (green-blue) is placed below the Peltier element in the pocket.

3 Design and set-up of our experiment

The first step in setting up our experiment was combining the equipment components from the three SUITCEYES partners, the University of Leeds, the University of Borås and VU Amsterdam. In this section, the various components will be described and the possibilites and limitations of the experimental design will discussed.

3.1 Set-up

The thermal stimulation of the skin was provided by two independent Peltier elements (size 35×35 mm) that could be placed in knitted pockets on different body parts (see Figure 1). Each Peltier element was connected to a unit that comprised an Arduino Nano Microcontroller, an H-bridge and a thermistor, all built onto a single breadboard (see Figure 2) and connected to a computer-controlled power supply (Delta E 015-20). A Python script running on a Windows PC controlled the intensity and duration of the signals to the unit. Figure 3 shows a block diagram of the controller hardware. In the current set-up, the component termed 'actuator' is the Peltier element, but in future studies, this could also be, for example, a vibration motor, a servo motor or a linear actuator. The intensity of the stimulation could both be positive and negative, resulting in either a warming or a cooling of the Peltier elements with respect to baseline temperature, which was intended to be close to skin temperature.

3.2 Knitted textile structure

Textile samples were designed and manufactured by flat knitting. Flat knitting is an industrial production method and industrial machines (Stoll GmbH) were used. Knitting enables incorporation of different materials (such as having different thermal conductivities), gives elasticity (used together with so-called shrinking yarns to create a patchwork with different densities, see below) and is in need of relatively small pre-adjustments before production. The textile prototypes (see Figure 4) consist of normal polyamide bulk

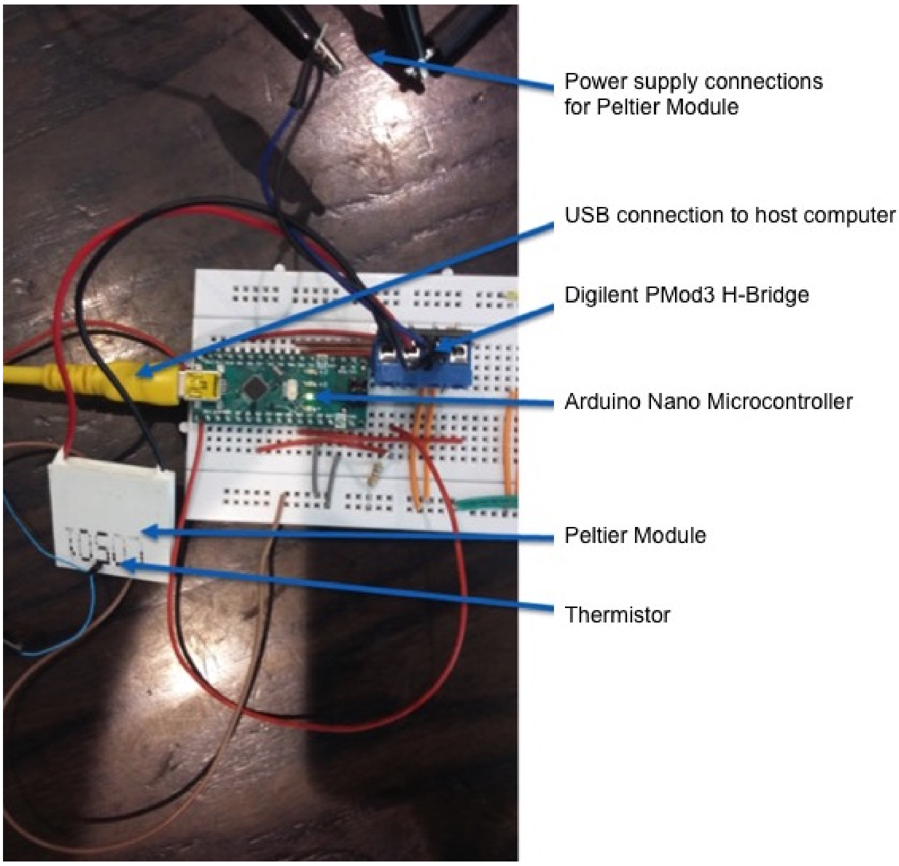


Figure 2: Set-up. Breadboard on which the arduino's and the H-bridges are placed (only one half visible).

yarn (white) and metal (silver pleated) yarns. Yarns chosen are having a high contrast of thermal conductivity. The metal constructions are forming what could be termed thermal patches. Peltier elements were placed in pockets beneath these patches thus protecting the brittle Peltier element and in total creating a soft thermally controllable interface towards the skin.

Swatches were used as such, but also made into straps (see Figure 2a) with an adjustable belt. This is the first kind of preliminary prototype for a full-fledged Haptic Intelligent Personalised Interface, HIPI. By the strap construction both positioning on different body parts could be done as well as changing the internal distance between two patches.

3.3 Calibration of the thermistors

The output of the thermistors is a voltage in mV, but for the experiments it is important to know the temperature in degrees Celcius. Therefore, both thermistors had to be calibrated. Water of different temperatures between 8 and 40°C was created by mixing hot and cold water (18 different values). The thermistors were placed for about 20 s in the glass of water. The temperature as measured by a mercury thermometer provided the actual

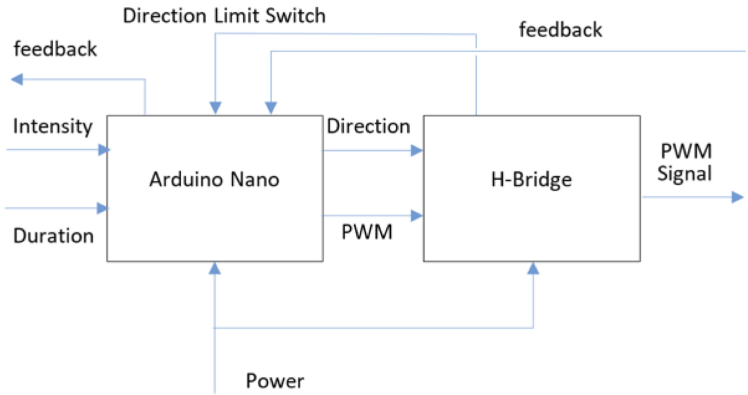


Figure 3: Block diagram of controller hardware. PWM stands for Pulse-Width Modulation Signal. More details about this controller can be found in Deliverable 5.2.

water temperature. The temperatures were mostly measured from warm to cold, but to check for hysteresis effects, some values were measured in random order.

The result of the calibration is shown in Figure 5. The red and blue dots show data for the two thermistors. Within the measured range (which is the range that is relevant for the present purposes), the relationship between the output of the thermistor and the actual temperature turned out to be highly linear ($y = 258 + 11.6x$ and $y = 252 + 11.2x$ for the two thermistors, respectively); in both cases, the coefficient of determination R^2 was 0.998.

3.4 Selection and optimization of experiment characteristics

Several informal pilot experiments were performed to test the usefulness and reliability of various aspects of the equipment and the design.

Heat generation
When Peltier elements are stimulated, they transport heat from one side of contact to the other side, so they can be used to either cool or warm an object. Cooling can only work properly if the transported heat can actually be removed into some heat sink. The current set-up does not provide such a heat sink, as these are usually heavy and take up a lot of space, which is unsuitable for a HIPI. The consequence was, that even when the thermal stimulation was set to cooling, after some time the Peltier element warmed up again. Therefore, the decision was made to only use warm stimuli in the actual experiments. In the near future, it will be tested whether it is possible to create a knitted structure that could work as heat sink.

Another finding was that it takes a substantial amount of time for the Peltier elements to cool down to baseline temperature after the control signal stopped. Whereas the control signal had very steep on and offsets, the temperature profiles of the Peltier elements as shown by the thermistors were very shallow and had a significant time delay. This is an aspect of the set-up that should be taken into account. A limited rise of the baseline temperature from trial to trial is acceptable, but care should be taken that the

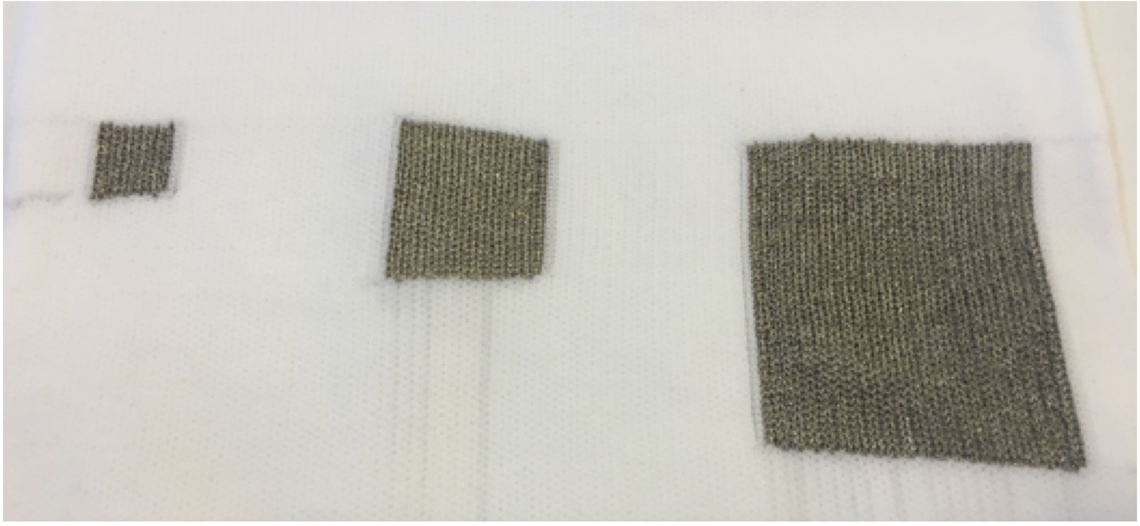


Figure 4: The front side of the textile sample to be facing the skin. Polyamide (white) with intarsia knitted patches of metal silver yarns. Here, three sizes of these patches are shown, but a large number of constructions have been made. The middle one is having approximately the same size as the Peltier element. The total swatch is about 30 by 20 cm. Peltier elements are to be placed beneath these patches.

stimulation does not become too warm and uncomfortable for the participants. The conclusion was that blocks of trials should be limited to 10 trials, after which the Peltier elements should actively be cooled down to skin temperature. This was done by placing them for a short time on a aluminium block in a coolbox.

Auditory information
The onset of the stimulation was slightly audible as the power supply produced a brief click. Especially in experiments where a participant has to detect whether or not there is stimulation, other cues are unwanted. Therefore, in all experiments, hearing of the participants will be reduced by having them wear ear muffs.

Stimulus duration
Stimulus duration had to be long enough for the Peltier element to warm up, but also as short as possible to limit trial time. The aim of the current experiments was not to investigate which duration is optimal, so the only requirement was to choose a stimulus duration that was useful. All subsequent experiments will have a stimulus duration of 5000 ms.

Stimulus intensity
The intensity of the stimulus was controlled by the power to the Peltier element. For the current experiments, the PWM signal was either on (100%) or off (0%) providing a power of 7.5 W or 0 W, respectively.

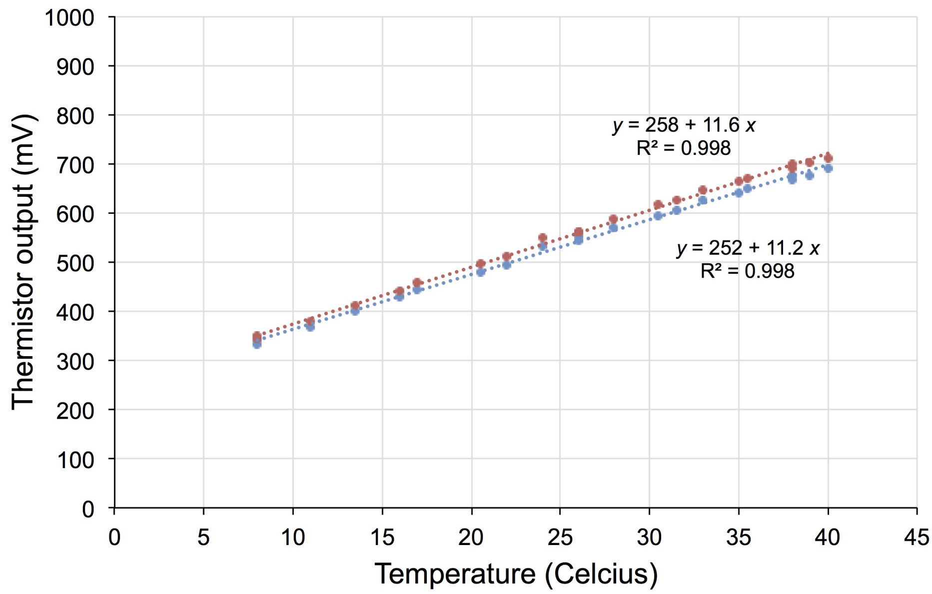


Figure 5: Calibration of the thermistors. The red and blue data points belong to the two different thermistors. It can be seen that over this temperature range, the relationship is linear.

Concentration
Detecting whether or where a thermal stimulus is given to the skin turned out to be quite hard. Participants really had to concentrate on the locations where the Peltier elements were placed. For better concentration, participants will be required to have their eyes closed or be blindfolded.

4 Experiment

4.1 General methods

4.1.1 Participants

The three experimenters were also the three participants. Participants 1 and 2 are females, participant 3 male.

The research program was approved by the Ethical Committee of the Department of Human Movement Sciences, Faculty of Behavioural and Movement Sciences, VU Amsterdam. The experiments were carried out in accordance with the approved guidelines.

4.1.2 Procedure

At the start of each experiment, the Peltier elements were placed in the knitted pockets that were strapped to the arm(s) of the participant. The exact locations depended on the experiment. Participants put on the ear muffs and closed their eyes.

In the experiments, participants had to decide either which Peltier element warmed up first, or which one warmed up. They had to respond by pressing on either response button ‘1’ or ‘2’ (see Figure 6). Only after finishing all trials of a block did they receive any feedback about the correctness of their answer.

Temperature of the Peltier elements as measured by the thermistors placed in the knitted pocket below the Peltier element was written to file with a frequency of 60 Hz, as were the on- and offsets of the control signal and the responses of the participant.

Room temperature was about 23°C.

4.2 Experiment 1: Discrimination of temporal order

4.2.1 Method

Two Peltier elements were placed on the volar side of the forearm. The placement was halfway between elbow and wrist (see Figure 6). In Condition 1, the distance between the sides of the two elements was 2 cm, in Condition 2, this distance was 6 cm. After a verbal sign of the experimenter, the first stimulus was presented after a random time interval of between 500 and 3000 ms. The second stimulus appeared after a delay of 0, 2500 or 5000 ms. Which of the two Peltier elements was warming up first was pseudo-randomized, such that both elements were used an equal number of times as first and as second. Task of the participant was to indicate which element was perceived to warm up first by pressing either the button marked ‘1’ or marked ‘2’ (see Figure 6). Responding that both elements warmed up at the same time was not allowed. A block of stimuli consisted of 5 trials, namely the 5 different combinations of Peltier element and delay. Trials within a block were presented in random order.

Participant 1 performed three blocks of Condition 1 and two of Condition 2. Her skin temperature was 28.5°C. Participant 2 performed two blocks of Condition 2. Her skin temperature was 29.5°C

4.2.2 Results and discussion

In most of the trials with different onsets in both Conditions 1 and 2, the actual stimulus onset of the two stimuli was indeed different. In these cases, the participants were able to correctly identify the element that warmed up first. Unfortunately, over the course of the five trials in a block, the baseline temperature of the elements rose substantially (about 1 or 2°C per trial). As a consequence, the temperature of the stimulus that was presented as second, was sometimes higher at the start of the stimulation than the stimulus that was presented first. An example of such an occurence can be seen in Figure 7. This was quite confusing for the participants.

The task was experienced as very hard and full concentration was needed, even with the larger stimulus separation in Condition 2. Therefore it was decided to change the experimental paradigm to a simpler one, namely instead of determining the order of stimulation, participants had to decide which of two elements was stimulated.

4.3 Experiment 2: Which element warms up?

This experiment consisted of three different conditions in which the placement of the thermal stimulation varied. The hypothesis behind these variations was that the further

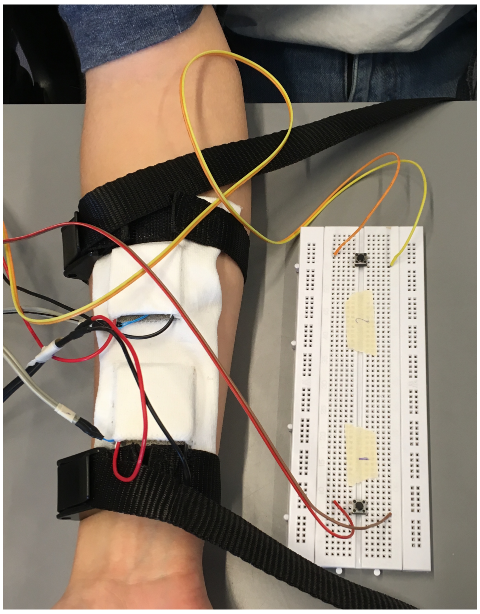


Figure 6: Stimuli on the right forearm. The two Peltier elements are placed in small pockets with a distance of 2 cm between the pockets (Condition 1). The knitted structure (not visible) directly touches the skin. The small black squares marked ‘1’ and ‘2’ are the response buttons.

away from each other the elements were placed, the easier it would be for the participant to decide which of the two elements was stimulated.

4.3.1 Method

In this experiment, always two Peltier elements were placed on the arm(s) and the task of the participant was to decide which one warmed up. In Condition 1, the elements were placed as in Condition 2 of Experiment 1 on the volar side of the forearm, and the interstimulus distance as measured from side to side was 6 cm. In Condition 2, one element was placed on the forearm, 10 cm from the elbow and the other element on the upper arm, also 10 cm from the elbow (see Figure 9a). In Condition 3, one stimulus was placed 10 cm from the elbow on the right upper arm, the other in a similar way on the left upper arm (see Figure 9b).

Blocks consisted of ten trials in which each element was stimulated five times, in random order. The participant had to respond with a button press, which of the two elements warmed up. In addition to the immediate response of the participant, it was also noted down if the participant wanted to change his/her answer at a later stage.

Participant 2 performed one block of Condition 1. Participant 3 performed two blocks of Condition 1 and one block of Conditions 2 and 3. His skin temperature varied between 29 and 30°C.

The second block of Condition 1 of Participant 3 was a control condition in which the thermistors were used to measure the skin temperature halfway between the two Peltier elements. This was done to check whether or not the skin temperature between

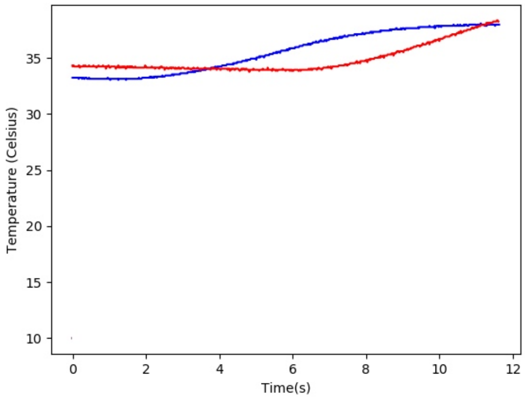


Figure 7: Example of temperature profiles that cross. The blue line shows the profile of the Peltier element that was stimulated first, but it can be seen that the temperature of the other Peltier element (indicated by the red curve) was higher at the start. As the task of the participant was to determine which of the two elements warmed up first, this was quite confusing.

the elements rose during the experiments. All participants experienced that the warmth of the stimulus after a while distributed over the whole forearm, making it very hard to decide which one was stimulated (first).

4.3.2 Results and discussion

The responses of participant 1 were at chance level. Often she hesitated or changed her response after a while (sometimes to a correct response, sometimes to an incorrect respones). Participant 2 performed slightly above chance, but also with much hesitation. Against the expectation, performance of participant 2 in Condition 2 was at chance level. Apparently, placing the Peltier elements on different body parts (forearm and upper arm) did not facilitate the task. Finally, in Condition 3 the participant scored 100% correct.

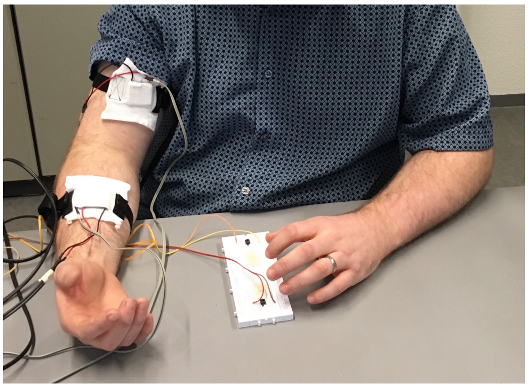


Figure 8: Stimuli on the volar side of the right forearm and upper arm.

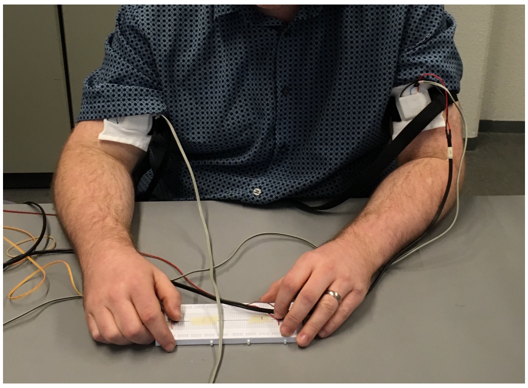
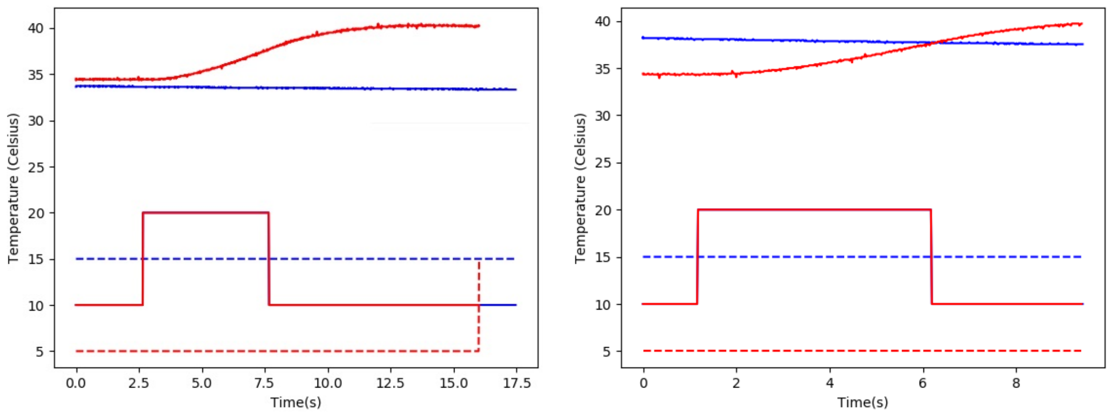


Figure 9: Stimuli on the volar sides of the right and left upper arms.



(a)   (b)

Figure 10: Graphs of the temperature (red and blue lines) of the Peltier elements as registered by the thermistors. The two upper lines show the temperatures of the thermistors. The red solid line below indicates the control signal (arbitrary scale). The dashed lines indicate button presses (if any). In (a) the stimulated Peltier element is indeed warmer than the other one. The steep rise in the red dashed line indicates that the participant has made a decision (in this case a correct one). In (b) the baseline temperature of the not stimulated element is much higher than that of the stimulated element. Note the different time scales of (a) and (b).

The temperatures measured in the control condition clearly showed that the skin temperture halfway between the Peltier elements remained constant during the block. Therefore, the errors made by the participants could not be due to the whole skin of the forearm actually warming up.

In all conditions, the baseline temperature of the Peltier elements rose from about 30 to 36°C or even 39°C during a block. Examples can be seen in Figure 10. In a) the Peltier element that was stimulated indeed rose in temperature, both actually and in comparison to the other element. However, in b) an example can be seen where the temperature of the other element is much higher at the start than that of the stimulated element and only after about 5 s becomes the stimulated Peltier element actually warmer. This was very confusing for the participants.

5 General discussion

The aim of the current experiments was to determine whether thermal stimulation would be a suitable option for implementation in a HIPI (Haptic Intelligent Personalised Interface). There were several aspects that needed to be evaluated, namely the hardware, the software, the textiles and performance of the participants.

All components of the hardware worked well. However, the Peltier elements needed substantial time to warm up or cool down. Of course, this was known in advance as the rise or fall in temperature cannot be instantaneous. However, after warming up or cooling down the element has to go back to baseline temperature. Without a proper heat sink, this turned out to be impossible. When the stimulus was set for cooling down, this worked only for a short time, as the necessary warmth created at the other side of the element was soon conducted also to the 'cooling' side. When the stimulus was set for warming up, this worked well, but the temperature remained high after the stimulation stopped. Over a few subsequent trials, the baseline temperature rose substantially and further stimulation was not possible to avoid painful stimuli. So Peltier elements will only be useful in situations where only few subsequent stimulations are necessary, unless a proper heat sink would be available.

As these issues with the Peltier element render them unsuitable for further exploration, it was not possible at this time to compare the various textile prototypes. One thing that will be tested in the near future is whether it is possible to create a suitable heat sink from a knitted fabric.

Performance of participants was overall quite poor. They needed full concentration and found the various tasks extremely hard, even though they were able to perform above chance level in most cases. It should be noted, however, that our participants received hardly any practice trials. It remains to be seen how easy or how hard it would be to improve performance over a series of practice trials. Performance in our epxeriments, was slightly better than reported by Halvey et al. (2011), who found detection rates of 0.47 and 0.36 for nylon and cotton patches, respectively. An important difference between their experiment and ours is that our patches are made of metal, which has a higher heat conductivity than both nylon and cotton. In addition, our participants were alerted to the approximate time of stimulation, whereas such information was not available to the participants of Halvey et al. (2011).

Part of the difficulty in our experiment arose from the unwanted rise of the baseline temperature of the Peltier elements. It is likely, that it was confusing to participants if they had to identify the element that was warming up while the other element was already at a higher temperature. However, this cannot be the only reason for the difficulty of the task as, very interestingly, all participants experienced a rising of the skin temperature in between the stimuli, whereas the actual halfway temperature remained constant.

6 Conclusions

A review of the literature shows that there is increasing interest in applying thermal stimulation in other contexts than presenting stimulation to the hand. This review also showed that the existing number of studies is still quite limited and mostly preliminary in nature. Therefore, our investigations into the possible use of thermal stimulation in a HIPI is timely and of general interest. It is worthwhile to continue our efforts to improve the various components of the set-up.

A first step that needs to be made is adding some sort of heat sink to the Peltier element, so that after stimulation, the temperature can go back to baseline temperature much more rapidly than is currently the case. Investigations in Workpackage 5 look into the possibility of creating a knitted textile that can function as a heat sink. A working heat sink would also create the possibility to use 'cooling' stimuli. Several studies showed that cooling is detected faster than warming (e.g. Bolton et al., 2015; Stevens and Choo, 1998; Wilson et al., 2011) and has lower thresholds (e.g. Gray et al., 1982). Once this first step has been taken, the plan is to study thermal detection and discrimination at more body sites and for both cooling and warming.

The literature and our own study also showed that thermal stimulation in a HIPI will probably not be useful for conveying complicated messages. However, not all information transmitted through a HIPI needs to be complex. Appliciations such as a thermal hug by means of a thermal harness (Gooch and Watts, 2010) might be worth investigating. Workpackage 2 will provide more information about the needs and wishes of people with deafblindness and the expectation is that there will be quite a variety in their preferences and needs. Therefore, it will be valuable to continue research into the potential of thermal stimulation.

Finally, it was informally observed that participants felt that their whole skin warmed up, whereas the actual stimulation was provided at two distinct locations. Control measurements showed that the skin temperatures in between these locations did not warm up. This shows an interesting perceptual phenomenon that is of fundamental interest. We intend to pursue this phenomenon in more detail in follow-up studies.

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