Graduation Thesis | Media Technology MSc program | Leiden University

Calming pressure

A study through design on stress reduction by deep pressure touch contractions through wearable technology.

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Abstract

Stress (and anxiety) complaints tend to become more pervasive in today's life [3, 21]. Reducing levels of stress is becoming of more importance for mental wellbeing due to its negative consequences for our health [7, 5]. Therefore, a way to lower our levels of stress would be invaluable. The crossover between stress and ever more present wearable technology show such devices would be promising. Deep Pressure Touch, a technique to reduce stress by adding pressure on the body, is known for its therapeutic calming effect [7, 8, 10, 25]. In this study, the researcher developed a wearable device, Premo, and tested its effectiveness in reducing stress levels while performing tasks. A tailored system had to be designed because of the lack of existing adaptive Deep Pressure Touch systems and the novel inclusion of the use of rhythm instead of continuous pressure.

This paper starts by outlining stress, deep pressure touch, related wearable technologies, rhythm and social synchronicity. Followed by highlighting the gap in the field leading up the design guidelines for such a device. In order to answer the research question, a device was designed following the design guidelines which was tested on participants when performing a stressful task. The research sheds light on the design processes, potential strengths and advice for future studies.

In this paper it is presented how a research-through-design method contributes to the exploration of design for our mental health. It is also argued that the integration of psychological insights with wearable technology makes way for an engaging area of research and enables more meaningful technologies.

'**Premo**' means *pressure* in the universal language of Esperanto. /'premo/

Preface

I think I was four years old when it started: a tension in my stomach. I didn't know what it was. I called it "the feeling". I've tried a lot, from medical examinations to therapies to alternative medicine. Later I got to know it was stress that had evolved into anxiety. Still today this anxiety disorder is present in my life and therefore I know how gruesome it can be. Then my grandmother got Alzheimer's disease and became more and more stressed, crying anxiously, it was morbid to witness. This motivated me to try and make the lives of stressed and anxious people a little bit more comfortable. The opening scene is based on this dream - together with my 'oma kippen'. Hopefully, more practical solutions can be found which can comfort this horrendous feeling. In order to do my bit, I made this project entirely open source and it is based on accessible materials and tools.

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Big Hero 6, an animation film about a softrobot designed for healthcare. ©*Walt Disney Pictures*

Chapter 1

Introduction

These days I often wear the 'scarf' my eldest son Aron gave me. He's a sweet boy but sadly he works hard and can't always be there at every moment. As support for my 'days that could be better' (as he put it), he gave me this 'scarf'. It relaxes me. My memory is not what it used to be anymore, you know. Sometimes I forget that this is my home now and I do not know where I am and what am I doing here... Or when I have to go to the doctor. Those things frighten me, my dear. I don't like it when that happens. Oh my, this heart isn't the youngest anymore you know? The other day I had a hospital appointment coming up. The nurse of my elderly home told me in the morning. This 'scarf' sensed that I became disquiet and it contracted softly. After a while, when the nurse was long gone, I found a note that said 'hospital appointment 3 o'clock'. "I don't want to go!" I became more and more stressed out. The 'scarf' noticed my tension and started to contract, putting slow rhythmic pressure on my body. Feeling this made me feel safe and it reminded me of when I was a child. How mother tucked me in bed firmly under the sheets. The 'scarf' rhythm became slower and slower until there was no pressure at all anymore. A few minutes later Aaron came in to pick me up. I told him I didn't want to go but at least I wasn't as stressed anymore as I used to be. "You will be alright mom" and Aron hugged me.

This fictional scenario is about Margaret who lives in an elderly home and suffers from anxiety because of Alzheimer's disease. The 'scarf' (called "Premo") is a wearable technology based upon 'deep pressure touch'. The scenario outlines a possible application of Premo in a fictional real world example in order to grasp the potential of such a device. Margaret experienced the feeling of the pressure as comforting and in this case, it reminds her of the safety of her mother. The 'scarf' sensed her agitation by collecting physiological data from her body. Because of this data, it can act accordingly to the situation by applying different pressure patterns in different scenarios. This helps Margaret to cope with stress when Aron isn't around.

1.1 Social relevance

Anxiety and stress are a growing epidemic in modern society [3, 21]. When the mind perceives a threat, physical or psychological, it automatically results in a bodily condition that is called 'stress' [19] or 'anxiety' [8]. This can be favourable when we need to stay focused and careful in threatening situations. Albeit there are not as many physical threats currently psychological threats (social, work, etc) are becoming progressively pervasive for most people [5, 3]. More and more people suffer from stress and anxiety in modern society [2, 5, 21]. Persistent and or recurring exposures to stress can result in significant detrimental health consequences such as heart attacks, suppression of the immune system, burn-outs, depression and/or anxiety [2, 3, 5, 6]. Lowering stress levels is of increasing importance for mental healthcare [5] due to a high amount of physical and psychological morbidity [7, 5]. Thus a system that could reduce our levels of stress, preferably monitoring and reacting accordingly, would be invaluable. Deep Pressure Touch (abbreviated to DPT), pressure on the body, is known to have a calming effect [7, 8, 10, 25] on people suffering from tension.

The aim of this project is to investigate if the combination of rhythms and deep pressure touch could help people to relax. No previous research about the combination of these two approaches has been found until now. Therefore, "Deep Pressure Touch Contractions" (DPTC; combination of Deep Pressure Touch and rhythm) is a novel approach that is hypothesized effective to reduce stress levels. The goal of this paper is not to propose a cure for stress or anxiety. Rather, it is trying out a research by design approach to lay the foundation for and improve modalities exploring deep pressure touch.

Chapter 2

Background

Stress and anxiety are described by Helly (1980) as "the subjective experience of apprehension or tension, imposed by the expectation of danger or distress" [4]. It triggers all kinds of physiological and physical reactions aimed at retaining us from detrimental situations. The body and mind usually return to a calm state when the threat is dealt with or avoided. However, the state of being stressed is becoming more common [5]. Stress arises in modern society mainly from psychological rather than physical danger [5, 2]. Stress and anxiety can nest emotional, cognitive or physical reactions, making it strenuous to grasp the concept or measure it precisely [2]. A variety of therapeutic interventions exist like mindfulness practices [9] or cognitive therapies. Most of the therapeutic interventions in present-day depend upon learning cognitive skills [5]. However, it is known that touch [12 - 15] and in particular DPT [7, 8, 10, 25] can have beneficial effects.

In scientific research stress can be measured in two ways; subjective (the participant tells the researcher wat he or she feels) [8] or objective by bodily measurements [2, 3, 19]. When there is a threat, the brain releases chemicals which brings about certain bodily processes; a raced heartbeat, focused way of thinking, increased respiratory rate, moist withdrawn from the bowl (also known as the feeling of a knot in the stomach). Some of these symptoms can be measured by sensors like heart rate or galvanic skin response (sweat). These are highly correlated with the amount of stress a person experiences. [19, 44] More on the measurement of stress in chapter ‘ 5.1 Tools.

2.1 Effects of tactile stimuli

The tactile stimulations are known for its positive mental effects such as touching, holding, grooming, pressure and stroking [12]. Studies show gentle pressure is beneficial to the mental development of preterm infants[11] and the absence of touch can have serious consequences for physical health [11, 13] such as stress and anxiety [14]. Swaddling tightly or stroking demonstrate an increase in welfare for institutionalized babies [12]. Thus, the stimulus of the tactile senses can increase our mental health [11, 12] and release of dopamine [16].

Affective haptics is a research area that focuses on influencing the affective state of the user by tactile actuators which are programmed to follow interactive algorithms. Touch can communicate some sort of (unconscious) meaning. Two examples of this are *iFeel_IM!* [15] and the *Affective TouchCasting* [18]. The first is a system that conveys and augments the emotional experience during chat messaging. Affective TouchCasting explores how media can be enriched through haptic stimuli which is connected to affective responses and mapped over the torso. Affective haptics can be brought about through a combination of four channels [17, 45].

» Physical simulations; a rising nervous sensation (like pressure in the stomach) can literally be simulated by physical pressure on the stomach.
» Physical stimulation; like tickling or stroking
» Social touch; hugging, handshaking, tap on the shoulder.
» Design; shape, the texture of the material, temperature

This project draws knowledge from affective haptics by simulating breathing patterns into a physical simulation. Breathing patterns can have an effect on our mental states [see the chapter about 'Rhythm']. And this project draws inspiration for the location of the wearable Premo on the body similar to hugging (social touch) which has causality with comforting. Taking *social touch* into account in the design is important because the wearable enters the most intimate space of the wearer; onto the body.

2.2 Deep pressure touch

Deep pressure touch (DPT) is referred to as a type of tactile stimulation by applying pressure on the human body. This results in a feeling best described as hugging, firm touch, squeezing, holding or swaddling.

DPT is found to have a calming effect on people who are stressed or anxious. DPT is commonly used to manage stress levels of children who are diagnosed with autism disorder [7, 8, 10]. Less research is found to have trials with people who are not diagnosed with a mental disorder. Results from these studies show that they also benefit from DPT [10, 25]. They describe their experience as 'relaxing', 'safe' and 'comforting' [7, 10]. For subjects suffering from severe anxiety, DPT shows a greater effect [10]. Some studies even indicated that DPT intervention can have a calming and comforting effect on people suffering from stress, unrest and/or anxiety caused by Alzheimer's disease [24].

Advantages of DPT in clinical applications are that they are easy to apply, the intervention is non-invasive and has no known negative side effects. Also, it does not require constant cognitive efforts like other calming techniques [6, 9]. This is favourable for children with autism since they tend to have a lower level of attention [8, 25]. However, as with all therapeutic tools, it is well established that none is helpful to all [7, 8]. Some do respond better to deep pressure touch than others [10].

Famous research on DPT is done by GRANDIN [10] who developed a 'squeeze machine' aimed at people with autism disorder. The machine applies pressure to the sides of the body (fig 1) by an inward movement of two panels by which the subject is compressed. DPT used to be provided by the use of 'squeeze machines' [8, 10] or by a more clinical available modality for providing DPT namely 'weighted blankets' [7, 20, 25].

"For animals, the tickle of a fly landing on the skin may cause a cow to kick, but the firm touch of the farmer's hands quiets her."

- GARNIN TEMPLE

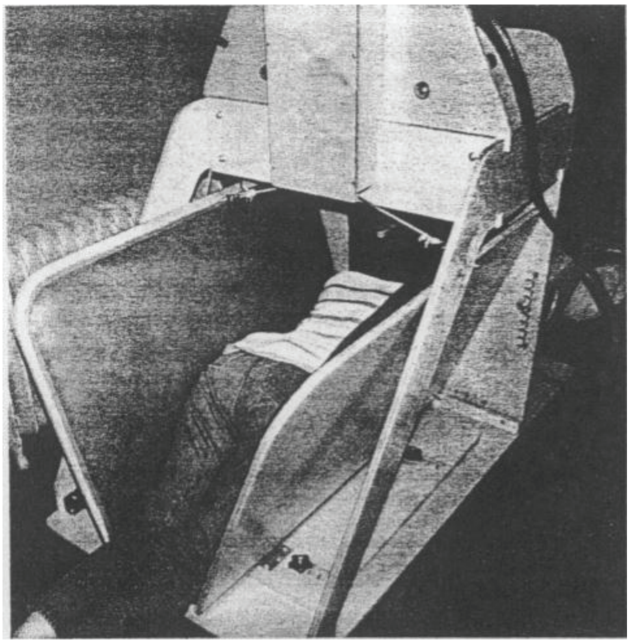

FIG 1 The rear view of the 'squeeze machine'. Here can be seen how the subject is positioned between two pressure plates.

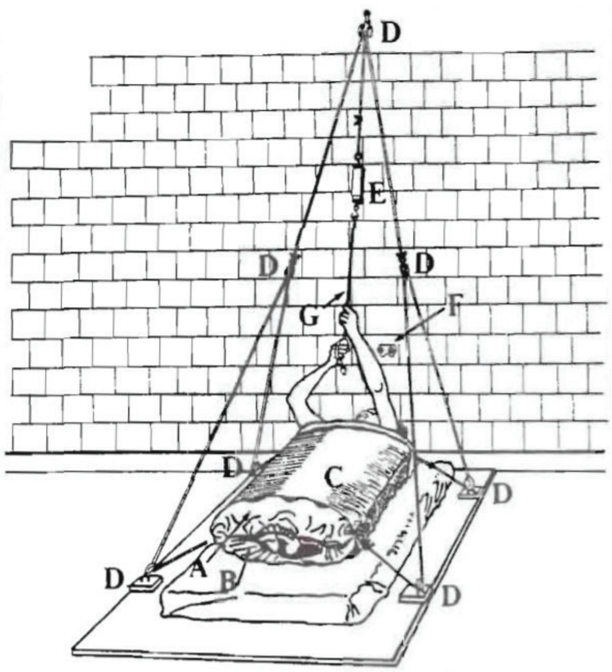

FIG 2 The "hug machine" from Krauss (1987).

2.3 *Wearable Technology [with DPT]*

In order to make DPT more accessible, a wearable device would be favourable. After all, stress can occur anywhere. Wearable technology has recently started becoming a real trend. As computing devices are becoming more powerful, tinier, and more connected to the available data on the web/cloud, the possibility arises for devices with more mobility, personal experience and close proximity to the body for sensory input and actuator output. Examples in the realm of wellbeing include the fitness tracker *Fitbit* [40], a wearable that tracks your alcohol intake called *Proof*, the *eMosquito* for diabetes patients, smart tattoos that monitor your sun exposure or skin fluids (*Dermal Abyss*) [41], the neurostimulation device that sits on the back of your neck *Thync Relax Pro*, smart jewellery like the *Bellabeat* and the *Spire Stone* that help you breathe, and many more could be listed here. Few examples are in existence within the domain of DPT though.

A DPT wearable that is scientifically studied is the *weighted vest* , similar to a *weighted blanket*. These studies test the effectiveness of on-task behaviour and impulse control. Attention of those vests for children with a disorder like attention deficit hyperactivity disorder (ADHD) [31, 33] or autism [32, 34]. When wearing the vest, children experience significant improvements. They exhibit calmer behaviour and this suggests to be a remedy for on-task behavioural problems.

A commercially available product is the *Squease vest* which has been specifically developed for children with autism disorders. The vest allows for a protected feel and calming effect when it applies pressure to the torso. No scientific research could be identified with this product in the literature. The disadvantage of the *Squease vest* is not only its price tag of 300 euros at the day of writing but also the need to hand-operated the vest. It is questionable if it is favourable for people (with autism disorder) who are stressed/anxious to have the cognitive ability to bear in mind to hand-operated the vest in the moment. Because of the price tag, some DIY (Do It Yourself) solutions have emerged.[1, 2] These solutions, that are made by the moms of autistic children, are made from Velcro sport bands and apply continuous pressure around the waist.

2.4 *Novel approach*

All found devices have been created to support uninterrupted DPT on the lateral or dorsal parts of the body. None have been found to deviate from this type of continuous application of DPT. Research has shown rhythm like breathing or sound can be beneficial for mental health [29, 30, 42]. This research tries to fill in this gap in DPT research.

2.5 *Rhythm*

Several studies found 'rhythm' to have a positive effect on mental state. Our respiratory output is not only influenced by but has also an influence on our amygdala activity [29]. Breathing in a slow oscillations pattern is used to help people suffering from stress, anxiety and depression [29 - 30]. Zelano et.al. (2016) Shows how slow patterns in breathing '*synchronizes electrical activity in human piriform (olfactory) cortex, as well as in limbic-related brain areas, including the amygdala and hippocampus.*' [30, p189]

Rhythm is one of two primary ambits of music [43]. A strong link is present between psychological processes and rhythm [43]: theories of music recognize that music can have a calming affective influence on listeners [42]. Even apes (tamarin) showed a decreased activity and increased calm behaviour when they were exposed to 'tamarin affective vocalization based music' [43]. Adult humans show an increase of well-being, reduced depression and increased norepinephrine levels when listening to music featuring certain pitch, timbre and rhythm[42]. To conclude, it is speculated that rhythmic patterns have the potential to have a calming effect on humans. Not only humans have the inclination to get in sync

1. Easy Low-Budget DIY Sensory Vest. From: http://ibreakcrayons.blogspot.com/2013/12/easy-low-budget-diy-sensory-vest.html
2. Do-it-yourself deep pressure vest. From: http://masonjosias.blogspot.com/2012/02/do-it-yourself-deep-pressure-vest.html

with a rhythm, rhythms can also have a calming effect on our mental states.

Hypothesized is that by the use of rhythmic oscillations, the phenomenon of spontaneous synchronisation takes place. Humans have the unintentional tendency to be in sync with oscillating rhythm surroundings and take unconscious effort to be in sync [26, 27]. It is suggested that this spontaneous in-phase coordinated behaviour can be seen in aligned leg movement when walking next to each other. This project aims to investigate whether a combination of rhythm of contraction and DPT has a calming effect. It could be possible such synchronization occurs between the rhythm of the contractions and the rhythm of the participants breathing.

In a study by Richardson et.al. (2007) patterns of coordination were observed which demonstrated that unintentional spontaneous synchronization of rocking chair movements was 'constrained by the self-organizing dynamics of a coupled oscillator system' [26, p867]. Oullier et.al. (2008) argued the occurrence takes place because of the two-way exchange of perceived information, even if the participants were not specifically briefed to coordinate. They also state that the influence of the coordinated behaviour remained after the encounter when the information exchanges had been withdrawn (because of social memory).

> *"The same spontaneous syncronization happends in the animal kingdom. The synchronous chirping of crickets is constrained by auditory coupling and the fireflies synchronize their flashing by visual coupling constraints"*
>
> - Richardson et.all. [26, p885]

Chapter3

Research question

As a result of the prior research the following question arises:

Is it possible to calm people down by deep pressure touch in combination with physical rhythm when taking a stressful task?

Therefore, the hypothesis of this study were as follows:

» The application of DPTC (combination of Deep Pressure Touch and rhythm) would reduce subjective and objective* stress during the performance task.

» Participants would perform better with DPTC on a stressful task.

*autonomous bodily reactions

Inorder to answer, a research through design (RtD) approach is chosen. A tailored system needs to be designed because of the lack of any existing adaptive DPT systems and the novel inclusion of the rhythm aspect. RtD is gaining popularity in the scientific community [1, 23]. Innovation no longer comes from a market pull but from a more contextual push such as scientific studies, like this one, which delivers insights about what people might want or need in the future [1]. The iterative design process of RtD generates insights and force the researcher be concrete [23], due to a constant *"struggle with opportunities and constraints, with implications of theoretical goals/constructs, and the confrontation between these and the empirical realities in the world* [23]" which RtD enables. Developing Premo was central to the knowledge-generating process. It provoked discussions because it made the theory perceivable. It is believed such an approach promotes gaining an actionable understanding of the dynamics of such a device. Due to an iterative design process, the quality of the devices improves.

A side goal of the writer is to conduct research that could be done by every maker. Using widely available and cheap materials it is believed it potentially makes the project accessible for further development by an audience that is not that well funded. Plans on how to build Premo will be made available online.

First, design guidelines resulting from theoretical research are drawn up and are revised after every prototype. The final design guidelines are stated below and will be discussed in the discussion section. The final device will be built accordingly and used to create a final revision of those guidelines. The main test of the final product will consist of a random two-period crossover design setup. This method is used to balance the variation of two conditions (on and off) while the subject is undergoing a stressful test (the stressor).

Chapter4

Design Iterations

In order to test some principles but to save time and resources, some small prototypes were built. The main 3 iterations can be seen below along with the gained insights from building and testing the prototypes.

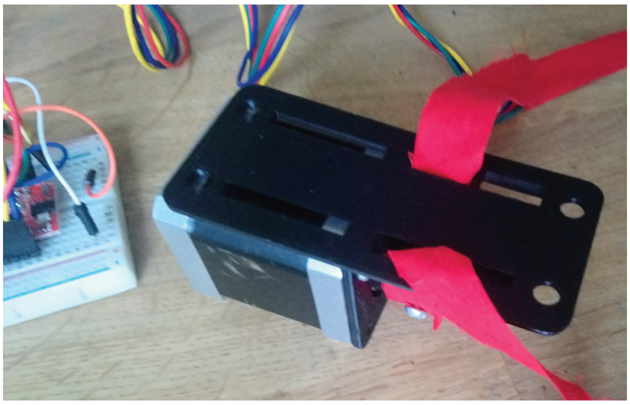

Fig 3 Prototype 1

The first was a simple mockup to test the feeling of the contractions. The wrist was chosen for this. The wrist of the person can be placed on the black frame when the two pieces of fabric are bound around the wrist. Pulling of the motor provided DPT. It enabled experimenting on the timing of the pressure. However, due to technical limitations and uncomfortable wristband, an improved version was needed.

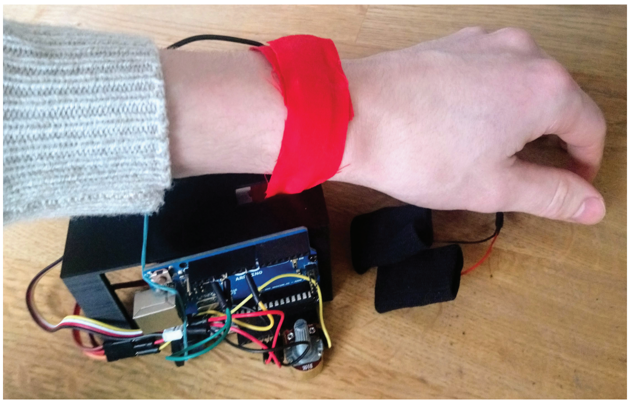

Fig 4 Prototype 2

This prototype was tested with 7 subjects while playing the stressful game “the moron test” while hooked up to a Galvanic Skin Response (GSR) sensor. The goal of this test was not to take measurements but to test the device itself. The motor appeared to be strong enough. People struggled to play the game since they could not move one arm because it was attached to the device. Some people (N=3) thought the noise of the servo was a bit distracting. People got still stressed from movements that were to fast. These have to be more gradual.

Scaling the motor principle up would be impossible therefore an air pressure system was chosen in order to pressurize the device. After talking to subjects it was noted that the device gave more a “pulling” rather than a “pressure” sensation. It is believed that air pressure will provide the intended pressure.

Fig 4 Prototype 3

FIG 5 Prototype 4

The plastic band was bound to the top of the torso just under the arms. Through a Wizard of Oz method, subjects (N=4) played again 'the moron test' game. Feedback was overall positive, it felt more comfortable and gradual increase of pressure made the device less distracting. However, pressure area and placement on the body were not optimal in order to have a more calming effect. Later a fabric version was developed and it was used to experiment with different locations on the body. This version could also contract (inflate).

4.1 *Design guidelines*

The theoretical and practical research led to insights translated to the following design guidelines which can be used for designing of DPTC wearables. These have been iterated to the final version below. Premo has been made accordingly. For each guideline, the implementation into the project will be explained.

#1 Approachable

In order to prevent aversion because of a technical and/or medical look, the wearable must blend in the daily characteristics of the wearer as much as possible as well as leaving an approachable and safe impression. *Implementation: An example could be roundings instead of sharp edges and match the style of daily clothing/accessories and the use of friendly materials and colours.*

#2 Intimacy and appropriate behaviour

A unique feature of the tactile sense is that it needs to be closely pressed against the person, in order to be perceived. This, in contrast to most other senses, not only has the consequence that it is in close proximity physically but psychologically as well. A wearable device has its natural property to operate in the intimacy of personal space (physical intimacy). To enable a more smooth integration of technology into the human physical environment, it must possess suitable proxemic characteristics and appropriate behaviour [35]. Its behaviour must be 'rounded' like its appearance. The increase of the contractions is gradual, not binary.

Implementation: The contractions are less noticeable when the device is just turned on - gradual increasing its intensity (timing and applied pressure). The same is true for when the device needs to turn off. This prevents too much attention being drawn to the device and prevents the device to become a stressor.

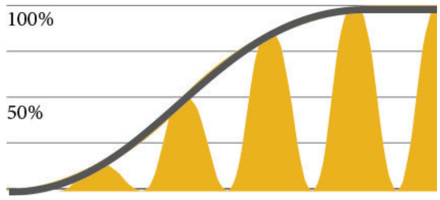

FIG 5 Visualisation of the gradual contractions

3 Meaninfull placement

Choosing the right location for this is key because some areas of the body are more intimate than others [36] and the wearable could potentially be too invasive. Other body parts convey a different meaning through culture. Inspiration from 'hugging' is drawn because of its close connection to calming, soothing, comfort and safety.

Implementation: After an initial pilot study with participants using self-reports, different kinds of hugs were indexed and it was examined for each of the involved parts of the body to which extent people find them 'intimate' [36] - the shoulder (blades), upper front torso and upper back were chosen. These locations are key pressure areas involved in hugging and considered least intimate in relation to other types of hugs. An example of a non-favourable hug-feeling is the 'waist hug'. This type of hug is considered more intimate because as Turnbull et al. (2014) suggest; the shoulder blades are considered less intimate than the hips/sides.

From this pilot study, the current way of wearing (see fig 6) was ultimately chosen as the most appropriate *considering comfort, contact points (association with 'a hug') and technical feasibility. The pressure area on the front of the body is intentionally not used because a pressure band on the torso of a female participant was in every case uncomfortable. (Note: there is no intent to simulate a hug as lifelike as possible.)*

#4 Meaningful simulation

Drawing from the domain of affective haptics, the physical simulation of breathing will be used because of its direct correlation with stress (respiratory frequency increases when stress levels increase) and because of the location on the wearable on the body (upper body). It is hypothesized that spontaneous synchronization of breathing might take place, intensifying the calming effect of DPT.

Implementation: The wearable will follow the respiratory frequency of 0.1Hz (inhale 4s, exhale 6s). It is suggested that this is a particularly calm breathing pattern [19] because HRV (heart rate variability) is generally observed at around this breathing frequency. Heartbeats occur in a certain rhythm (heart rate). Fluctuations in the time between beats is a physiological phenomenon known as HRV. Fluctuations in HRV appear both randomly and rhythmically. Analysis of these fluctuations shows 'significantly correlated rhythmic oscillations indicated by a peak at a frequency around (...) 0.1hz'. [22].

Fig 6 Three of de nine ways thought up to wear Premo with the pressure points in mind.

#5 Wearability

Given the nature of the context of Premo, wearing & stress relieving, the wearable has to be comfortable and not hinder the wearer's actions while completing the test sessions. Therefore it may not be too heavy, sizable for an optimal fit, be made of flexible material and the form may not hinder. Experimenting during the design process determined the values of these characteristics.

Implementation: Premo will be made of soft and flexible materials in a friendly colour. Initially, it was planned to sew the electronics on Premo. However, this appeared too heavy for a comfortable fit. Due to thoughtfully placed velcro, Premo can adapt to every physique.

4.2 Prototyping the final design

Inorder to get the final prototype to operate research has been done into pneumatic systems; different material, sealing patterns and methods [37]. After self-tests; non-stretch plastic, double sealed seams and air pockets of 15mm wide seem to be the strongest and most effective in terms of shrinking. This plastic band is 15cm wide and 2.5 meters long and will be placed into a sewed cotton 'sock'. Trough a custom designed and 3D printed connector a hose can be connected - airtight.

An Arduino microcontroller is used for timing purposes of pneumatic actuators and a 'Grove GSR' board. Air is controlled by a solenoid valve and an aquarium air pump valve (operated by a servo motor). The intensity of the airflow can be regulated ánd air can be let in/out through just one tube due to clever placement of these components and a custom designed tube system-optimizing wearability and approachability.

The Galvanic Skin Response (GSR) is also hooked up to the Arduino and potentially could control the entire system. Background on how stress will be measured will be found in sub-chapter 'tools'. Pictures and schematics electronics can be found in the digital appendix.

Fig 7 Final design.

Chapter5

Experiment setup

A mixed research methodology, the use of a combination of qualitative and quantitative tools, are used because this is considered a reliable way to measure the effectiveness of therapeutic interventions [7]. It is understood that background, gender and age can have influences on mental processing and responding.

Before any testing began, consent, age and gender information about the participants were collected. The subjects were individually introduced to the equipment, room and the procedures of the experiment. Stress, because of the novelty of the participant's experience, might influence test results. Therefore the equipment and test procedure were thoroughly explained. At all test sessions, subjects were wearing the wearable to prevent influence just by wearing Premo. The study was conducted in a quiet living room at room temperature with no other people except the researcher and participant.

Participants had to sign an informed consent form where the purpose of this research was stated: to study the reaction and performance on a mental arithmetic task with and without the wearable "Premo". Participants were free to withdraw at any time without giving reasons and were encouraged to ask questions before the test began. And they were free to ask any questions they might have.

The researcher believes there are by the best of his knowledge no known risks associated with this research study for normal healthy people. However, the task can evoke stress and slight discomfort. Therefore people with heart diseases or who are oversensitive for stress should be excluded from this research.

5.1 Tools

For mental stress indicators, the STAI-6 (State-Trait Anxiety Inventory) form was chosen. STAI is an established method for measuring stress/tension/anxiety[8] and consisted of 40 questions. It has been chosen because it is proven to be accurate [8] and the results can be easily measured and compared among participants (in contrast to an interview). Marteau en Bekker (1992) develop a shorter version with 6 questions. Research has indicated that the 6 form is almost just as effective in measuring stress/anxiety as the original STAI-Y form [38]. Using the 6 items version enabled for smoother test sessions, reduced errors and 'boredom' by participants. The STAI-6 form was given right after each test session. This will help answer hypothesis 1.

As previously stated, bodily changes because of arousal, like stress, can be measured. Although a high arousal level does not automatically signify a high level of stress, the two are strongly correlated [44]. When human stress levels rise, blood pressure and temperature rise. In order to dissipate the heat, sweat production increases. This spontaneous, unconscious reaction is evidence for the activation of the sympathetic nervous system. Galvanic skin response (GSR) measures the varying skin resistance because of this sweat. Measuring GSR was chosen as a physical indicator for stress because GSR is well-established and applied in psychological research for measuring stress/anxiety [2, 3, 44] and it is obtainable as a DIY kit. This GSR sensor measures resistance. When people get stressed (high aural) their body heat goes up and therefore their perspiration. The hand is very sensitive for that (clammy hands) so minor changes can be detected by the GSR. A higher GSR means less conductivity, means less perspiration and therefore lower stress levels.

It is hypothesized that on-task performance is also an indicator of stress. When people are stressed they are likely to make more mistakes [39]. Stress tends to influence the ability to think clearly. Therefore, the number of errors participants make will be counted for each of the two conditions and compared to see if they performed better with DPTC than without. Data from the stressful task will help answer hypothesis 2.

5.2 *Stressors*

The stressor will consist of a stressful task and its context (social pressure). During the design phase, it showed that not everyone experiences the same stress from a task. Therefore, the following stressors are tried out due to its broad representative of cognitive and social stress experience in everyday life. They are known to induce stress in a broad sample of people. A Mathematics test has been chosen among several other options (Stroop test, work memory, reflexes and agility). Due to the limited participant group and the duration of the experiment, it has been chosen not to use multiple stressful tasks.

The custom build math test program consists of random additions and subtraction equations consisting of two 2-3 digit numbers where deduction sums can never be negative. Participants were not allowed to skip an equation or use any tools. After answering feedback was given about whether it was correct (in green) or incorrect (in red) with the correct answer along with the given answer. During the test, the participant was shown a progress bar of how many correct answers were given of 30. This to motivate them to complete as many equations as possible in the given time. When the current goal was achieved a 'higher' level was achieved and the target amount of correct answers was risen by 5. The second progress bar showed the percentage of wrong answers emphasis every mistake they made. The system kept track of every equation where either the answer was correct and the time needed to answer. This way data about the total amount of completed equations, total (in)correct answers, total time and average time was gathered.

In modern life, stress arises mainly from psychological rather than physical threats. Hence, this experiment will also consist of a social stressor. For a stressful context, the participants were at the beginning of the experiment explicitly told they had to perform well on some simple tasks that everyone could do. They would be scored and compared to other participants - creating social pressure. A timer of 7 min counting down was in clear visual sight of the participant - creating time pressure. The researcher was seated next to the participant - occasionally looking over the shoulder of the participant - creating more tension. This all created a social pressure to perform. Grandin (1992) showed 5-10 min in DPT would be sufficient for a maximized calming effect [10]. Participants were told they were going to wear a device that created pressure but not explicit with the goal to calm them down. Participants received headphone with a timer sound to increase time pressure and additionally the headphones blocks out sound from the pneumatic system.

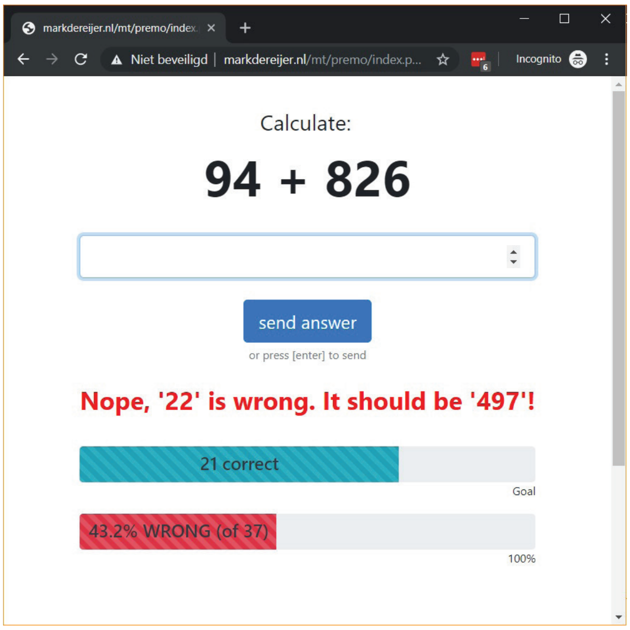

Fig 8 Interface of the math test

5.3 *Procedure*

By random allocation and a planned crossover design participants were divided into two groups. All who participated had two task sessions; half the subjects received DPTC the first session followed by the control (no DPTC) and the other half of the group the reverse (see fig 9). Each test began with 10 minutes of guided meditation from HEADSPACE (c).

Then they worked on the math task for 7 minutes. Depending on the assigned group, after 30 seconds Premo was gradually turned on (or was kept off). GSR data were collected while participants worked on the task in both cases. After each test session, people were asked to fill in the STAI survey. After the two task sessions, the participant was interviewed about their opinion on the wearable and personal relation to stress [see 6.3]. On average each trial took 50 min to complete. In the end, participants were told the whole reason of the wearable and experiment.

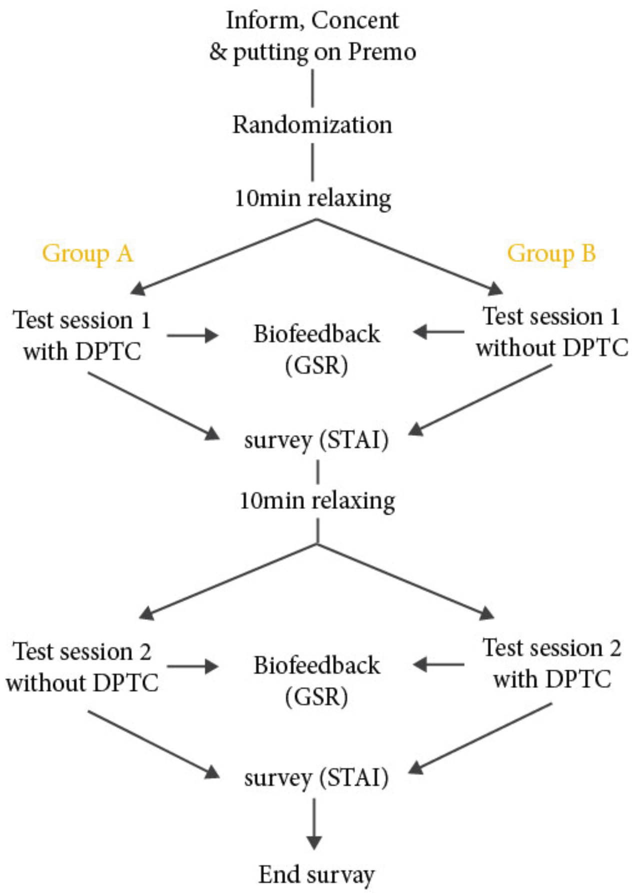

FIG 9 Experimental design overview.

CHAPTER6

Result

For all the data a paired samples t-test was used and a p-value of <.10 was established as a level of marginal significance. A *paired samples t-test* is used if the intervention effect takes place in the same sample group where observations can be mutually compared. The demographic characteristics of the participants are shown in Table 1. Table 2 presents an overview of the gathered data from the STAI, GSR data and math test.

6.1 *Demographic characteristics*

A convenience sample of N=8 participants took part in the study. The age range was 22-30 years, with a mean age of $\mu = 25 \pm SD = 2.7$. All participants completed the experiment and finished it in 50 minutes. After the test session, a small qualitative interview was conducted.

Characteristic	***Value***
Female	62.5%
Male	25%
Other	12.50%
Age	$\mu = 25$ (SD = 2.7)
Self-assessed stress sensitivity*	$\mu = 3.5$ (SD = 1.4)
Self-assessed ease to calm down*	$\mu = 4.3$ (SD = 1.3)

TABLE 2 Demographic characteristics of the participants. *On a scale of 1 to 6 where 1 is "not at all" and 6 is "very much".

Data set	*Premo*	*Mean*	*SD*	*t*	*df*	*sig*
STAI results	Activated	37.1	11.9	-.119	7	.909
	Deactivated	37.5	8.3			
Total amount of calculations made	Activated	32.4	8.3	-.477	7	.648
	Deactivated	33.4	5.2			
Number of calculations correct	Activated	28.9	8.3	.512	7	.624
	Deactivated	27.6	6.8			
Percentage of calculations correct	Activated	88.6%	5.2	2.025	7	.082*
	Deactivated	82.0%	9.4			
Number of calculations incorrect	Activated	3.5	1.6	-2.113	7	.072*
	Deactivated	5.8	2.7			
Percentage of calculations incorrect	Activated	11.4%	5.2	-2.024	7	.083*
	Deactivated	18.0%	9.4			
Average time needed to complete one calculation	Activated	13.9	4.4	.960	7	.369
	Deactivated	12.9	2.1			
Avarage GSR Data	Activated	190.5	73.3	-.876	7	.410
	Deactivated	212.5	64.3			

TABLE 1 Paired Samples Statistics.

**Marginal significant at 0.10.*

6.2 *Experiment*

The first hypotheses predicted that the application of deep pressure touch contractions would reduce stress during the performance task. No significant difference, t(7) = -.12, p = .909, was found in the subjective experience of the calming effects with DPTC as measured by the STAI. According to Marteau & Bekker [38], a STAI score of <= 34 is considered low/normal. A score of >= 36 is considered as high/stressful. Participants with Premo had on average a STAI score of M = 37.1 (SD = 11.9) and without Premo a score of 37.5 (SD = 8.3). No significant difference, t(7) = -.876, p = .410, was also found in the objective experience of the calming effects with DPTC measured by the GSR data as shown in table 2. Participants with Premo had on average a GSR score of M = 190.5 (SD = 73.3) and without Premo a score of M = 212.5 (SD = 64.3).

Hypothesized was that DPTC would help participants to perform better on a stressful task. A marginal significant effect was found to justify this hypothesize. No significant difference was found in the total amount of solved calculations t(7) = -.477, p = .648. Participants made on average M = 32.4 (SD=8.3) calculations with DPTC and made on average M =33.4 (SD = 5.2) calculation without DPTC. The average time needed to complete one calculation did also not differ significantly when Premo was activated in contrast to when it was not t(7) = -.960, p = .369. In fact, it was on average higher with (M = 13.9s, SD = 4.4s) than without M = 12.9s, SD = 2.1s). On average, participants given DPTC did make less mistakes solving the equations (M = 3.5, SD = 1.6), than those not given DPTC (M = 5.8, SD = 2.7). This difference was marginally significant at t(7) = -2.11, p = .072. No significant difference was found when looked at the total number of calculations made correctly t(7) = .51, p = .624.

However, no significant difference will be found when a participant solved the same amount of equations correctly with and without DPTC. If the total amount of made calculations is higher without DPTC, proportionately participants performed better with DPTC in relation to the total amount of calculations needed. Therefore the difference in the percentage of calculations solved (in)correct is relevant.

When looked at the percentage of incorrect calculations participants had around M=11.4% (SD = 2.5%) wrong with Premo activated and when Premo was deactivated M = 18.0% (SD = 9.4%) wrong. A marginally significant decrease in incorrect calculations can be seen t(7) = -2.02, p = .083. Participants solved a higher percentage from the total amount of calculations correctly when Premo was turned on (M = 88.56%, SD = 5.25%) in contrast to when Premo was turned off (M = 81%, SD = 9.4%). There is a marginal significant difference, t(7) = 2.03, p = .082, between those two samples.

After the test participants assessed themselves a mean stress sensitivity of 3.5 (SD = 1.4) which is slightly above average on a scale from 1 to 6. Participants find themselves easy to calm down with a score of 4.3 (SD = 1.3). There is no difference in their self-assessment of stress sensitivity and ability to calm down in relation to their scores on the STAI, GSR and math test.

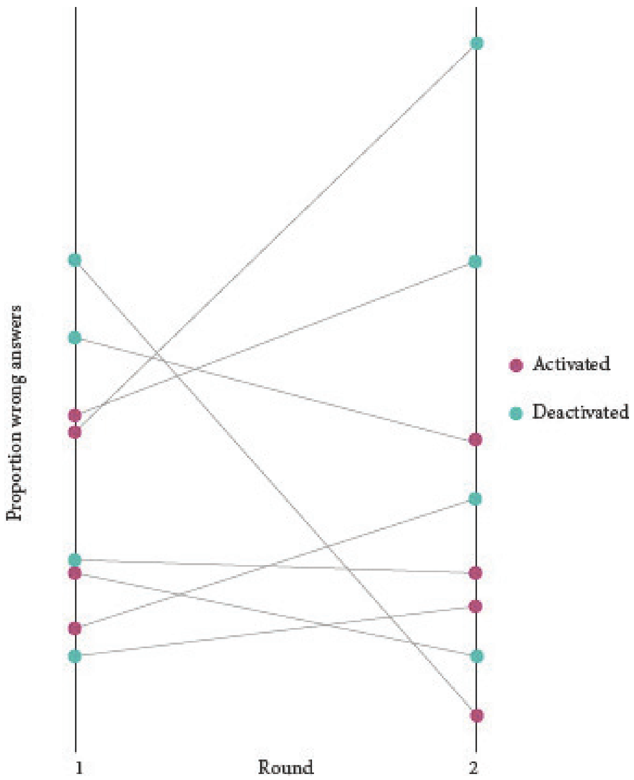

FIG 10 Proportion wrong answers relative to round 1 & 2. Participants who have an activated Premo the second round made less mistakes. Participants who have a deactivated Premo the second round made more mistakes compared to the first round.

Of the 8 participants, N=3 gave Premo a relative high score of 4/5 when asked: "Do you think Premo calmed you down?". Although the sample size is too small and thus no significant statements can be made, their average STAI score was lower (M = 32.2 SD = 3.8 N = 3) and average GSR score was higher* (M = 244.7 SD = 93.4 N = 3) when Premo was turned on. People who thought Premo did not calm themselves down scored on average high on the STAI (M = 40.0 SD = 14.5 N = 8) and had a lower GSR (M= 188.9 SD = 22.1 N = 8) when Premo was turned on.

*Higher GSR means more resistance, means less sweat production, means less arousal, calmer behaviour.

6.3 *Participants remarks*

During the experiment participants made on their initiative remarks about Premo and at the end a small interview was conducted*.

The interview covered the following questions:

- » How sensitive are you to stress? (rating 1-6) and why this rating?
- » How easily you can be calmed down when stressed? (rating 1-6) and why this rating?
- » Do you think Premo calmed you down? (rating 1-6) and why this rating?
- » Describe your experience; what do you think of Premo?
- » If you could buy Premo; When / where would you use it?

A discrepancy can be seen by Analyzing the remarks of the participant afterwards. Participants (N=3) who scored high on Premo's ability to calm them down described their experience as "a permanent hug", "it made me feel secure", "feeling of less environment, I become less distracted", "had the tendency to breathe the same way Premo contracted, slower", "it corrected my posture in a more alert pose". Participants (N=5) who scored low described their experience as "I startled every time it contracted", "it distracted me", "it felt like someone was tapping my shoulder for attention" and scored the calming effects low because "it held no relevance to me", "I don't like people touching me", "If it would apply a constant pressure it would calm me down better".

There is no relevance between the assessment of stress sensitivity and the ease with which participants are calm again and the assessment of Premo. As motivation for their rating stress vulnerability they gave varying personal answers like "I want to do everything right", "when there is a lot of being asked to me" or "I've learnt to put stress into perspective". Their motivation how easy they are calmed down after a stressful situation, participants gave an answer in the line of "I let go of it easily" or "it keeps stuck in my head".

The last question was asked to see how applicable Premo is into the participants' lives. Participants who thought it calmed them down related Premo to stressful situations (studying for an exam, or when dealing with an unpleasant person). Others couldn't answer.

*All the gathered data can be found in the digital appendix (see reference) under '*all gathered data > form responses*'.

Chapter7

Discussion & Evaluation

This study examined the effects of the combination of Deep pressure touch and rhythm for alleviating stress. Based on the measurements of a mix of quantitative (STAI, GSR, test performance) and qualitative (survey, observation) data were used to investigate the effects of DPTC provided by a wearable during a stressful task.

7.1 Effectiveness of DPTC

The hypothesis predicted that DPTC would lower objective and subjective stress and therefore increase performance. From the results outlined above, it must be concluded that in the studied sample the response to DPTC was not significantly different from the response without DTPC. As with all therapeutic interventions like this, it is well established that none is helpful to all [7, 8]. There were no significant differences in the STAI (subjective) as in GSR (objective) stress reduction. Though participants did not show significant calmer behaviour, they tend to perform slightly better (fig 10). There was a slight marginal difference in the correctness of answers of the participant. Other studies with weighted vest worn by children who suffer from an attention disorder (like ADHD) [32, 33, 34] show increased performance on on-task behaviour. It is argued that the pressured limited external stimuli. Another argument for the increased performance could be the focus on slow breathing because of the social synchronicity. Breathing and attention exercises like *mindfulness* show positive effects on people's doings [6].

Some of the people who said they benefited from DPTC during the test did not reflect this in the STAI and GSR as clearly. Regarding the STAI this could possibly have to do with the ability of the participant to self-assess. Participant filled in their self-assessment on stress sensitivity and ability to calm down after a stressful situation. Another reason could be that the 6-item long STAI is to general applicable for example 'I feel upset'. Questions could be more specific relate to the 'in the moment' 'short experienced' stress. Participants also tend to want to affirm the results if they got a hint of the reason of the research. They want to be too helpful. It could be argued that *Groove GSR sensor* was a bit too DIY and therefore produced too much noise in the data. The device is fairly new and only once scientific study [19] with the exact same device was found which makes comparing methodology and results difficult.

Some participants gave the feedback Premo had a calming effect because the rhythm of the contractions slowed down their breathing. As theorized social synchronicity would occur influencing breathing in a calming way. For future studies, a breathing sensor would be needed to measure whether this is the case.

It could be possible people tend to be less stressed and performed better in the second round regardless of DPTC. For example, two participants they came in the experiment stressed, one biked really hard to be on time. However, it could also be possible when they did the math tests for the second time it was not new to them anymore and therefore they could be less stressed the second time or at the second round, they had done a total of 20 minutes of meditation instead of 10 the first round. This statement could be falsified of justified by looking at the STAI and GSR results and significant performance from the first round vs the second round, again, regardless of DPTC. No significant difference can be found in both (see table 3) and therefore the statement could be rejected. Participants do not perform better or worse the second round with respect to the first round.

7.2 Design guidance

The design guidelines proved to be beneficial in the design process and could be helpful for future designers.

None of the participants found Premo scary because of a technical/medical look which would have been disadvantageous. Round shapes, keeping the tubes and other components out of sight, soft fabric and friendly colours are believed to help. Only the noise of the air compressor was a bit harsh for some participants and should be eliminated in future studies.

As said, Premo operates at an intimate place of a participant. By taking this into account in the design process it is believed almost participants fount Premo not to be intrusive. Only one of the participants found Premo really to be too intrusive. However, only because of its behaviour and not because of its placement on the body. The association with hugging was a good choice and even noticed by one participant. The gradual increasing intensity of the contractions is believed to let Premo to ease in more and to let it be a less intense experience than it would have been without a gradual increase. The contractions itself was, as said, for one participant too intense. He did not like to be touched in general.

Overall the wearability of Premo was high and none of the participants found Premo to be uncomfortable (no pinching or limiting body movements). Future designers should take this in high regard because uncomfortable fitting would increase stress levels by forehand.

Data set	*Round*	*Mean*	*SD*	*t*	*df*	*sig*
STAI results	1	37.1	12.4	-.119	7	.909
	2	37.5	7.5			
Percentage of calculations correct	1	85.5	6.0	.095	7	.927
	2	85.1	10.3			
Percentage of calculations incorrect	1	14.5	6.0	-.095	7	.927
	2	14.9	10.3			
GSR Data	1	204	63.5	.26	7	.803
	2	14.9	75.7			

TABLE 3 Experiment results relative to round 1 and 2.

No adverse design choices were noted but first improvements in the design of Premo could be made in the peripherals like the air compressor. Perhaps Premo could show more similarities with casual clothing be more integrated and to be more discrete.

7.3 *Reflection on RtD methodology*

Finally, I will reflect on the chosen RtD method. RtD indicates activities that play an important role in understanding the topic at hand. Actions like framing and reframing, iterating the prototypes, conducting small side experiments for knowledge generation that formed the base design/research decisions, provoked discussion, struggling with constraints, engaging physically with the subject and formed a platform for interactions and new ones came into existence.

Building the prototypes gave direction to the unfolding research like placement on the body and its behaviour and need for further study into affective haptics. And it forced to make it explicit in detail.

Testing Premo made us focus on the user experience which tells something about its generalisability, as said it could be more effective in a different context. The device, Premo, is itself an artefact of sharing the in this paper presented insights because the research can be physically experienced.

7.4 *Future directions*

From this research, there emerged some findings that could guide future research towards a revised research design and hopefully more conclusive findings on the effects of DPTC.

For further research, a larger participant pool should be used. The results are less based on coincidence when more people participate. A significant effect can emerge more clearly with the result of 100 people rather than 8. It may be that it works for a certain subset of the population only, like many stress-reducing interventions. However, this is less visible when using a low number of participants. With the current number, a quantitative analysis of subgroups is not possible.

The experiment itself, which was stressful, has possibly influenced their assessment. It could be argued that they had a lowered confidence at the end because many felt that they had performed poorly on the math test and therefore scored themselves differently than if they had done it beforehand. However, these questions might hint at the actual reason for this research - influencing their results that way.

During the test-sessions was in this case not technically possible to investigate the effects of continuous pressure during a round. Future research has to point out if continuous pressure instead of rhythmic would have a different effect.

Participants noted positive remarks about the calming effects - even if this was not reflected in their data. Perhaps is a stressful performance task with social performance pressure is not the optimal context for DPTC. Premo could potentially perform better in a different context. For example, one where Premo supports the participant in an attentive way who aims intentionally to become calmer. It could possibly be true that Premo should have been activated during the meditation session in contrast to the math test. Premo would become the pivot point of attention instead of destruction when something else is the centre of attention.

References

The digital appendix holds digital data such as photos, data sheets, 3d models, code, this paper, links, videos, used materials, etc. It can be found on www.markdereijer.nl/premo.

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