HapSync

Exploring Emotional Interactions Through Haptic Vibrations

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August 2021

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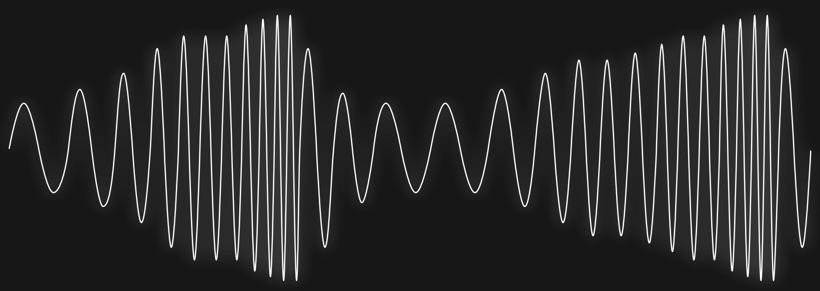

Foreword

HapSync is the last step of a journey that has marked these last two years at TU Delft, my exploration of human emotional interaction through technology, and also the richest and most meaningful of them. These last six months have proven to be some of the most challenging and intense that I can remember, and have taken me to places that I would have never imagined back in September of 2019.

It has taken time to understand the value and the uniqueness of what I have achieved surrounded by many incredible people, and I could not be happier with the result. It is sometimes hard to find the meaning and the contribution of the work I have done, especially in a field of which I still feel like I have little knowledge about, but I am proud and delighted with what I have achieved.

As I said, this project would have not been the same without many people that have supported me and who I am grateful that have joined me in this ride:

First, to my supervisory team.

Gijs: You boarded the train the last, but this project could not have happened without you. I could not have asked for a better fellow autonomous system to guide me and help me in every step of the way. Thanks for your patience, support and sense-making.

Derek: Thanks for receiving me with open arms into your world and helping me find my way this last year and a half. Although it has sometimes been challenging, you have pushed me to enjoy the journey and encouraged me to look through the lens of exploration rather than results, which led to some of the best moments of the project.

Dan: I can't imagine where I would have ended up if you had not taken me into this crazyness of haptics and human interaction, but I am pretty sure it would have not been half as awesome. Thanks for pushing me every time we met to be better and to reflect on why I was doing all this.

To my friends here in Delft, you are one of the biggest reasons I could complete this project. A challenge as big as this I could have only undertaken having an amazing group of humans behind to keep me sane, happy and healthy. A special thanks to Pawel, Carlos, Paula and Sofia, who have accompanied me through this project and these two years.

To my family and friends back in Spain, your support and love has kept me through the long hours of this master pushing me to be the best I could. I hope I have made clear every time how grateful I am to have you at my side, and how much your support means to me. Thanks once again.

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Executive Summary

Human experience does not solely consist of exchanging and processing information, it is a rich multi-sensory experience. The technology used to communicate with each other sometimes does not contemplate the nature of this complexity, and falls short to deliver emotional social experiences.

This project explores the possibilities of one of the most important senses for environmental awareness, active touch, or haptics. Combining touch and kinesthetics, it is a sense for which, comparatively to ubiquitous visual and acoustic interfaces, technological advance has mostly been kept inside laboratories and research institutions.

The goal was **to support emotion eliciting social interaction through vibrotactile stimuli (VTS)**. Moreover, given the difference in nature of haptics compared to other sensory modalities, it was also necessary to find an interface to create and sustain this interaction.

This research involved 5 separate studies (Fig. 1). The first, *Sweet Sensations,* investigated consistencies in the aesthetic response to VTS. The second and third investigated the consistencies of effective haptic communication. The main outcomes of these experiments were:

- Continuous and interactive VTS suit interpersonal communication
- VTS' meaning is emergent from interaction

These insights, combined with the application of the principles of enactive interfaces and embodied interaction, brought the final outcome of the project: Vibrification. **Vibrification is the process of translating data into mechanical vibrations** that can be sensed through the skin.

This approach to the generation of VTS allowed to expand on the possibilities of this modality. And that is what the last 2 studies were about. These two experiments helped shape the exploration of Vibrification to create a final interaction.

The final proposed interaction used **VTS to communicate two participants through their Vibrified breath in order to elicit emotional and empathic responses**. To do so, a joint breathing session was designed as the final interaction.

To shape this final exploration, we used three research questions:

- Can Vibrified biosignals help support empathetic insight?
- How should Vibrification of biosignals be approached in order to support interpersonal interaction?
- Is Vibrification a viable option to support embodied interaction?

After a final design and experimentation run, the final outcomes of the project therefore are:

- It is possible to create an emotionally moving interaction through Vibrified breath
- A working prototype for Vibrifying breath
- The presentation of Vibrification as a field for future research

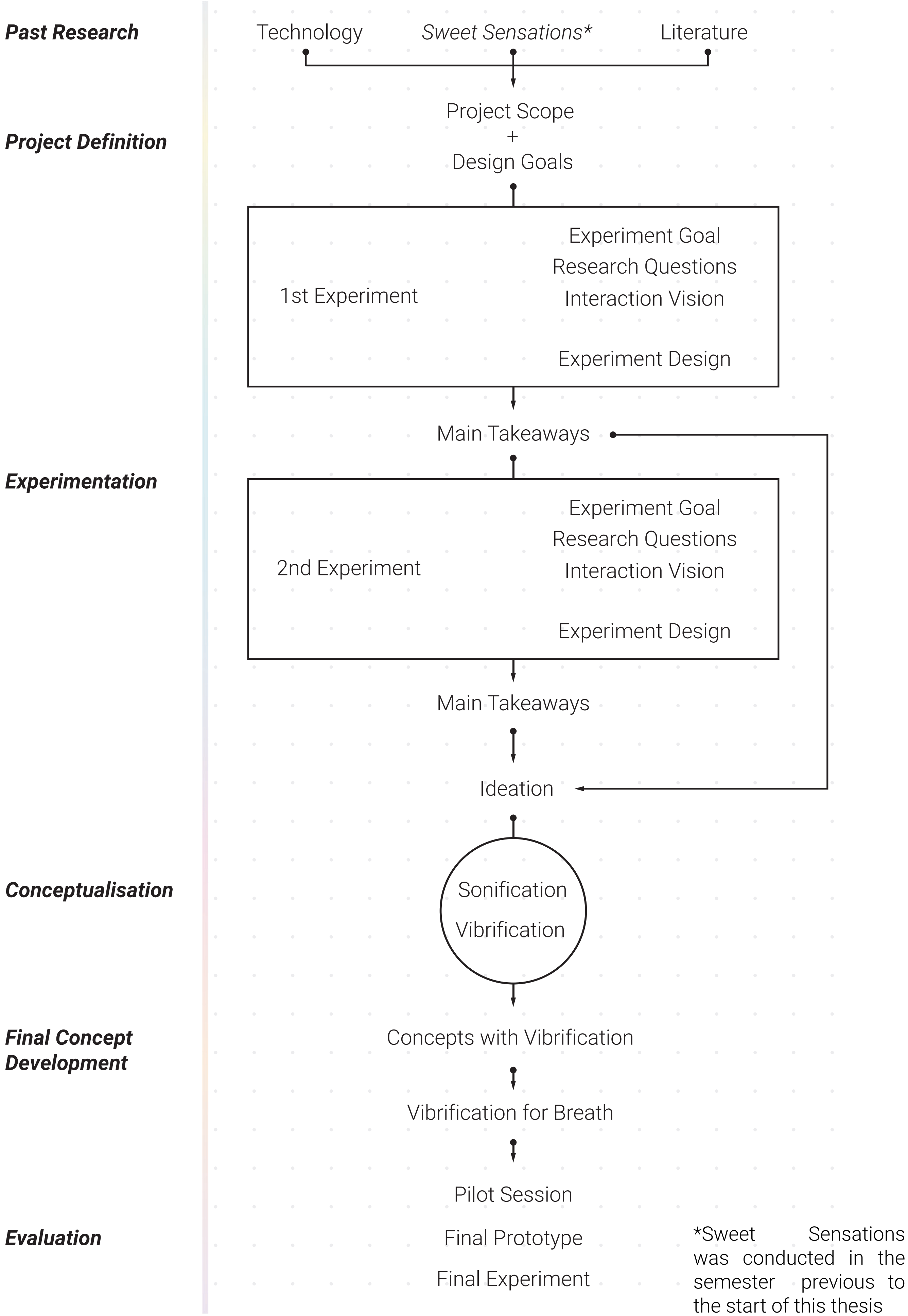


Fig. 1 - View of the process of the project

1. Digital Hugs

Let us start this introduction with two images. In the first one, two friends hug each other. One of them just got married, and both are celebrating this amazing moment, exultant and happy, and they melt in a hug. They feel each other, the breath, warmth and slight force through which they transmit the intensity of the moment (Fig. 2).

Fig. 2 - Me, hugging my friend

In the second, we see a person in a video call (Fig. 3). This is the way in which many people have interacted with their loved ones in the last 18 months and for expats like me, the best thing our digital technology provides us to keep in contact with our friends and family back home. At least you can see them; I remember when my sister was in the US back in 2008, and we had a special number card to talk to her on the phone at a reasonable rate.

Fig. 3 - Me, having a video call

There is no need to be a mastermind to see that there is a big difference between both pictures, and both interactions. Digital technology has advanced during the last 13 years, but there are still many things that it is still not able to do. The main direction in which digital technology has advanced focuses around our visual perception, and has left some of the rest of the sensory modalities in the background.

This has been happening since the beginning of computing, when cognitive science found a great analogy to explain how human cognition works: There is software and hardware, there is mind and there is body, and information is received and then processed inside our heads through mental models (Clark, 1996). It makes sense to develop technology for information to be transmitted and processed in the brain as easily as possible.

These technologies focus on the transfer of information, which is appropriate for certain tasks, but they have shortcomings in others. One of them is social interaction. Look at the hug, those are the types of interactions that cannot be replicated with visual interfaces because they rely on sensory modalities that are usually relegated to the periphery of the goal-oriented exchange of information, which is what those interfaces are designed to support.

In the last 25 years, some cognitive scientists have stepped out of traditional cognition and have developed new theories on how cognitive processes work. Embodied cognition (EC) and the enactive approach are examples of this shift, where the separation between body and mind is no more, and the process of cognition is seen as multi-sensory and emergent from the relationship of individuals with their environments, and each other (Gill, 2007) (Fig. 4).

These new perspectives have increased the interest of designers and engineers to develop new kinds of interfaces and interactions that leverage this dynamic and multi-modal cognition (Fig. 5). Enactive, natural (NUI) and tangible user interfaces (TUI) are some of these new trends that look for alternatives to visual interfaces, like haptic technology, to design and develop new interactions (Moussette, 2012; Müller, 2020).

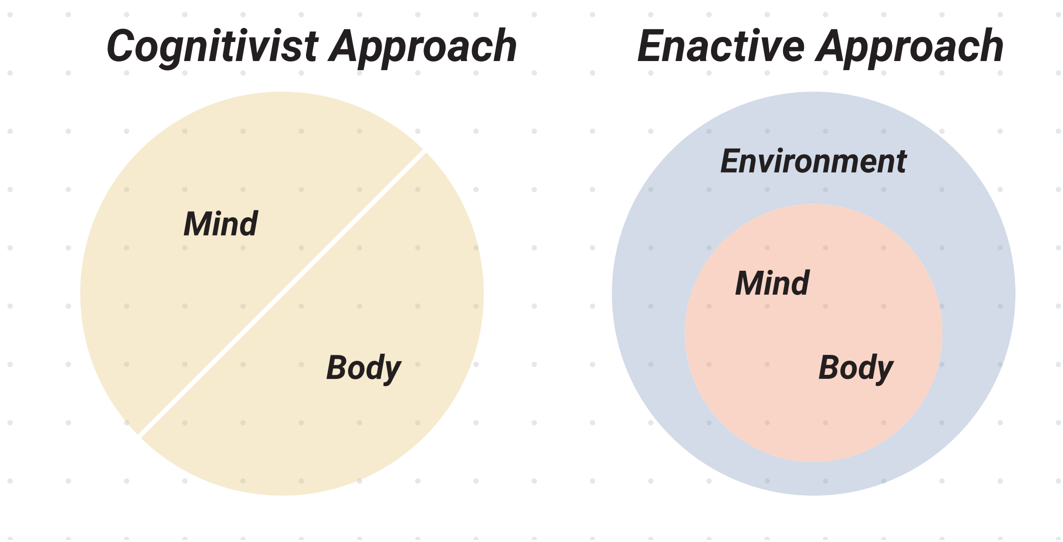


Fig. 4 - Representations of the Cognitivist and Enactive approaches

With the increase in interest, approaches and questions are appearing on how to design technology that are better suited to support the multi-modal nature of human cognition in novel interventions. This project rides this new wave of interface and interaction design.

HapSync is a project that explores the field of haptics, a sensory modality that is attracting more and more interest from the scientific community; and social interaction, looking for a way in which to capture what current digital interaction fails to transmit, the peripheral layers that make it meaningful.

After diving in the field and conducting several experiments on mediated interaction through tactile vibrations, the outcome of this exploration is *Vibrification* of biofeedback, or transforming biosignals of people into haptic vibrations. This allowed to transform and share intimate and emotionally loaded stimuli between participants in real-time. The resulting interaction, a joint breathing session where participants sensed breath through vibrations, turned out to be an experience that was intense, pleasant and immersive.

There is still a lot to explore on the possibilities of Vibrification of biofeedback: reciprocity in the interaction, the signals that can be *Vibrified*, bumping up the complexity of the tactile waveforms to create more complex stimuli, or the possibilities of different kinds of actuators.

This project only scratches the surface of the potential of this field of real-time communication of bio and non-bio signals through haptics, but it is a step towards more nuanced and emotion eliciting interactions, a step towards virtual hugs.

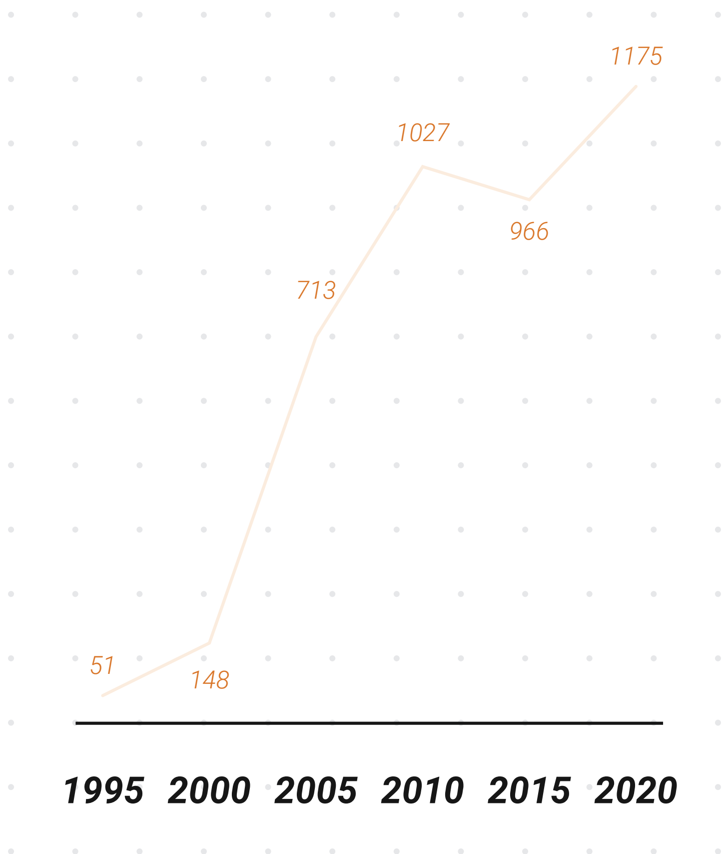


Fig. 5 - Interest is increasing in haptics, publications with the keyword "haptics" (Scopus)

2. Background

This project brings together cognitive science, design for interaction and haptic design as the background for the development of a new design intervention. It will start with a look to the current state of affairs in interaction design and its theoretical background. Then it will go through new approaches to cognition like embodied cognition or the enactive approach, and how those can affect the field of interaction design.

The main topic of this project is creating an emotion eliciting social interaction through haptics that implements the principles of those new approaches to interaction design. There will be different projects as examples of what has been done in the field.

2.1. The Current State of Digital Interfaces

2.1.1. Cognitivist Approach to Interaction Design

Modern User Interface (UI) Design has not advanced that much on the aspect of human sensory capabilities. In fact, interface and digital design have prioritised the visual sense as the way of interacting with our technology since a long time ago. This is due to different trends at different levels.

Parallel to the developments of digital technology, the field of cognitive science was experiencing a big increase in interest. In the 1950s, with the advent of computers, cognitive scientists took advantage of the duality of digital devices, software and hardware, and applied it to the process of cognition, dividing mind and body.

This comes from further back in time, from philosophers like Descartes and even a longer legacy of dualistic thinking (Anderson, 2003). Traditional cognitivism, then, contemplates cognition as the processing of information in mental models that represent the world and through which information is processed (Clark, 1996).

The effects of this cognitivist approach in design can be traced from the early steps of interaction design to the current landscape of omnipresent graphical interfaces. Camille Moussette's analysis in his PhD, *Simple Haptics* (2012), in which he elaborates on the effects at a product and interaction level, was very illustrative in that matter and was used extensively to develop this review.

Design has been related more to visuals than any other sensory modalities, in something that Juhani Pallasma, a Finnish architect, calls *Ocularism* (Pallasma, 2005) and he notes the limitations of this visual *focused* way of understanding human experience. He points out that there is a lot to the periphery of interaction and that there has been a disregard towards what happens outside of our focus.

> *"The essence of the lived experience is molded by hapticity and peripheral unfocused vision" (Pallasmaa, 2005, p. 10).*

The ubiquity of touchscreen devices in recent years has not helped to transition to *unfocused* interaction, with graphical interfaces still being the way of interacting with our devices on a daily basis. A nice visualization that Moussette makes is comparing two representations of O'Sullivan & Igoe's of *"How computers see us"* (2004) against the *mapping of the motor and sensory homunculus system* in the brain by Penfield and Boldrey (1937) to illustrate the difference between what the human body is tuned to do, and the limited nature of modern UI (Fig. 6).

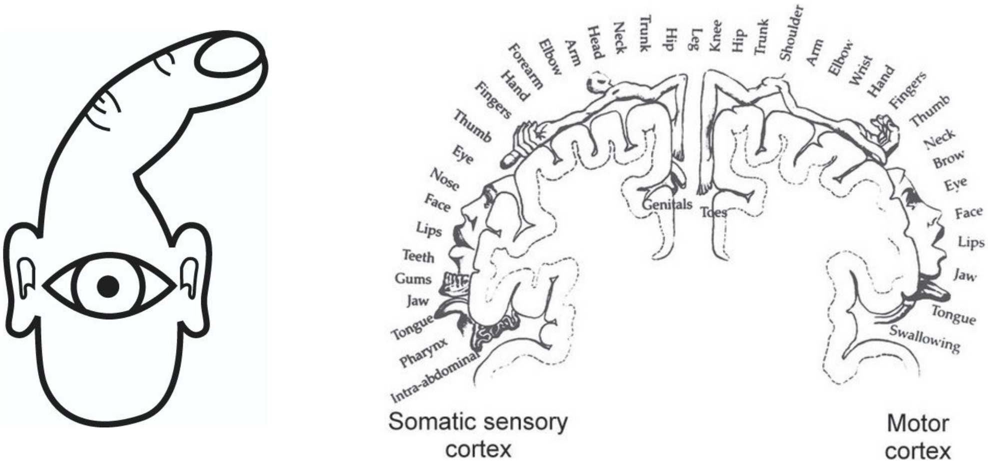


Fig. 6 - How computers see us (O'sullivan & Igoe) compared to the mapping of motor and sensory homunculus (Penfield & Boldrey)

It is quite surprising that even in environments where having physical interfaces is intuitively a superior way of interaction, they get replaced by touchscreen. A great example of this is the high end car sector, with companies like Porsche and Tesla ditching the traditional dials, buttons and even air vent controllers and putting them on the main touchscreen control (Fig. 7).

Multi-modal and multi-sensory interfaces have been kept mostly to laboratories and academic institutions and have not seen many mainstream applications. Riding a bike or playing an instrument are more physically engaging than what most digital technologies currently offer us, but recent trends seem to be aiming towards changing this.

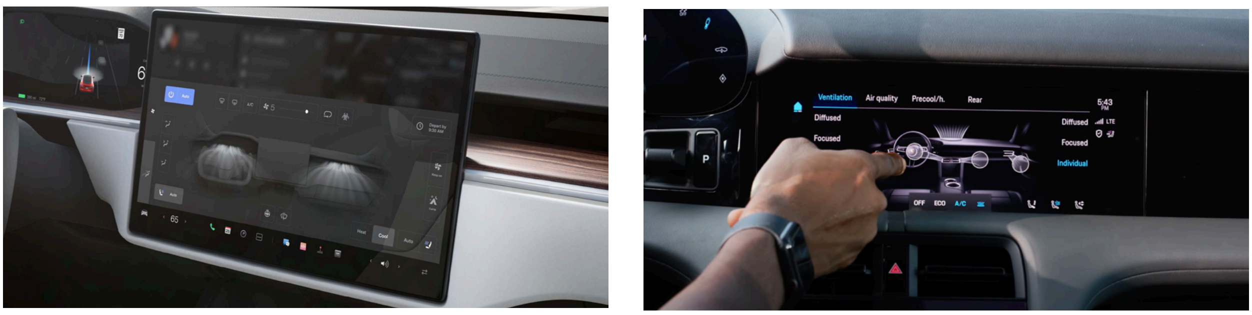


Fig. 7 - The interfaces to control the air conditioning vents in a Tesla and a Porsche Taycan (Tesla & MKBHD)

This trend in the development of digital interaction has also marked the use of technology to mediate communication with each other. The channels that we have available to communicate are also focused primarily around visuals and spoken language.

More and more channels are opening for us to interact in a mediated way, with applications and software like Instagram or Discord, to share live videos or chat and speak with friends, both using audio and video respectively. Big tech companies envision a future where VR (Virtual Reality) and AR (Augmented Reality) is the future of working and social life (Hern, 2021).

The COVID pandemic has made this transition even faster, as the rate of usage of video conferencing tools and software has grown significantly this last year and a half. These tools have helped stay in touch during difficult times and have helped combat some of the loneliness when it was impossible to visit loved ones.

But it has also generated what is called a burnout, especially in the work environment, where meetings have become continuous and have proven to be taxing for a number of reasons (Lee, 2020). Some of these reasons demonstrate exactly how these digital means of communication affect us compared to face-to-face communication: they overload our cognitive system and generate fatigue, and the effect of this in the longer term is still to be found.

2.1.2. Embodied Cognition in Interaction Design

In the last 25 years, a shift has happened on how the process of human cognition and the role of the body in it is understood, from being black boxes where things are processed (cognitivist approach) to being multi-modal and multi-sensory, involving and understanding the body as a whole (Sha, 2002). This way of understanding cognition is called Embodied Cognition (EC).

EC focuses its attention on how cognition appears in particular environments, with practical ends and exploiting external tools, making it a highly situated activity (Anderson, 2003). Approaches to cognition like the Enactive Approach give importance to the relational nature of perception and cognition, where the agent is an autonomous entity, navigating the world and making their own sense of it through action. As Varela, Thompson & Rosch put it in the foundational text of the enactive approach, *The Embodied Mind*:

> *"The mind exists dynamically in the relationship of the organism and their surroundings" (1991).*

A good analogy of what this means is how *The Embodied Mind* was supposed to be titled previous to its publication, *Worlds Without Ground*. This illustrates how within the enactive approach, the world has no inherent meaning, but emerges in a relation with the autonomous entity that is navigating it with the purpose of maintaining their autonomy. This process is called *sense-making* and is crucial in how cognition works within the Enactive Approach.

This challenge to traditional cognition is translating into trends that oppose how technology has been developing, instead of towards smaller, abstracted and almost immaterial (Burdek, 2005; Weiser 1991), the *tangible turn* as it is called (Moussette, 2012), aims for a more physical take on technology. Trends like physical computing, enactive interfaces, tangible user interfaces (TUI) or Natural User Interaction (NUI), although differing in focus, advocate for a bigger reliance on materiality and the rest of human sensorimotor capabilities.

This aligns with Klemmer et al.'s (2006) analysis on the importance of embodied interaction and the richness of knowledge through experience that this can bring to the table for the future of interaction design. They speak of the potential of embodied and physical interaction and how it can be taken into account in the design of future interfaces (Fig. 8).

When developing this project, the idea of creating interfaces for experience and EC was taken into account as a way of creating a more rich and engaging final interaction.

2.1.3. Participatory Sense-Making

The enactive approach has a very unique understanding of social interaction. De Jaegher and Di Paolo define it as follows:

> *"Regulated coupling between at least two autonomous agents, where the regulation is aimed at aspects of coupling itself so that it constitutes an emergent autonomous organization (...) without destroying in the process the autonomy of the agents involved" (2007, pp. 9).*

The key part of this definition is that interactions are on themselves autonomous processes, which cannot be understood by analysing the behaviour of the individuals that participate in it. The agents sustain the encounter, and the encounter influences the agents without destroying their autonomy.

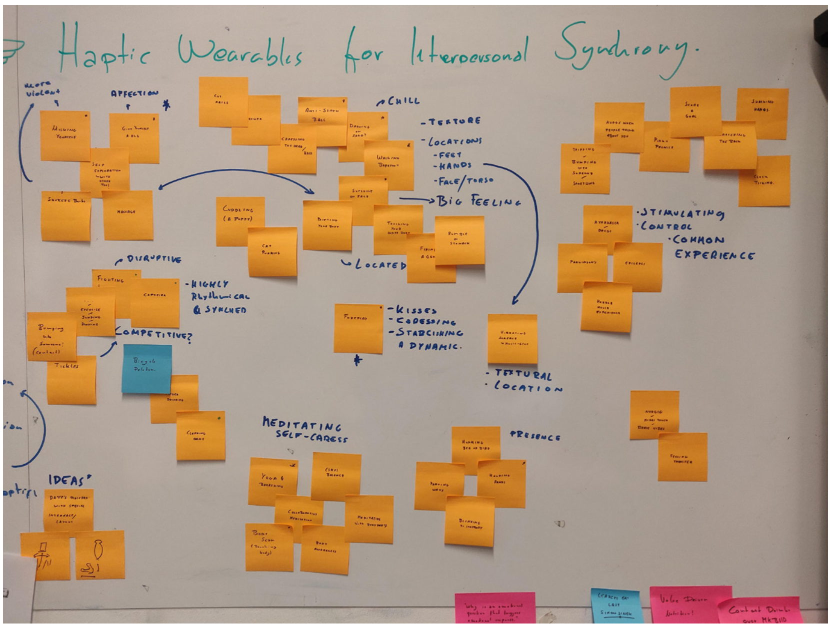


Fig. 8 - Richness of practice is one of the aspects of embodied interaction in Klemmer et al.'s analysis

A popular example of the autonomy of interactions is two people encountering in a narrow corridor, trying to get to the other side. They both try to get out of the way, mirroring each other's moves and ending up in front of each other again. Even though the participants do not wish to engage in this interaction, the interaction itself is sustained by the actions of both participants.

The dynamics and the meanings emergent within the interactions are heavily contextual and complex, and this coupling between individuals' sense-making into a process that is bigger than the individuals themselves is called *participatory sense-making*. These processes usually happen naturally face-to-face, but the limitations of digital devices cripple them in mediated interactions.

There is a fundamental conception that has framed the interactions with machines: the information theoretic signal transmission model (Shannon and Weaver, 1949). In this frame, information is passed linearly from speaker to listener. But as participatory sense-making defines, the different participants in the interaction are the ones that sustain it at all times, and listeners and speakers are in a continuous loop of communication (Gill, 2007).

How do the different parts of interaction, like coupling and regulation, happen in VTS mediated interaction would be one of the questions to answer in the following steps.

2.1.4. Interfaces for Embodied Interaction

This project is partly inspired by the enactive approach and EC, aiming to take the interaction out of screens and make better use of the sensory-motor capabilities of the human body. There has been related work, as different projects in the past have successfully implemented some of the aforementioned principles into interactions. These are some examples.

The Enactive Torch

The Enactive Torch is a prototype that applies the principles of the enactive concept of sense-making and exemplifies what Froese et al. (2012) call an *enactive interface* (Fig. 9). According to them, new technologies provide opportunities to create new ways of interactively experiencing the world, where interface is not the focus of the interaction, but the world is.

The enactive approach provides interface designers with a framework that considers both the sensory "input" and the motor "output" as part of the same process of creating meaning. Interfaces that are aimed to expand the possible interactions with the environment by leveraging this loop enable what they refer to as *augmented sense-making.*

This contrasts with what Froese et al. call the cognitivist approach to interfaces, which focuses on the computational properties of information processing and therefore the attention is forced to shift towards abstract information. These kinds of interfaces add a new step of processing information between perception and action, disrupting the sense-making process.

Enactive interfaces are then defined as *"technological interfaces that are designed for the purpose of augmented sense-making"* (Froese et al., 2012, pp. 4). And to illustrate this, they designed the *Enactive Torch*, a device that uses an ultrasonic distance sensor and a haptic actuator that acts like a distance sensing torch.

The principle behind the creation of such a device is the enactive view of tool usage, which dictates that tools become part of the sense-making process when they play a role on it, becoming "transparent", meaning that the tool is not experienced anymore, but the world through the tool is. They are not external input to the cognitive process, but they transform it (Havelange, 2010; Hutchins, 2010; Stewart, 2010). There is proof that tools are not just part of our environment, but their use has effects on our bodily ways of acting at even neurological levels (Kieliba et al, 2021).

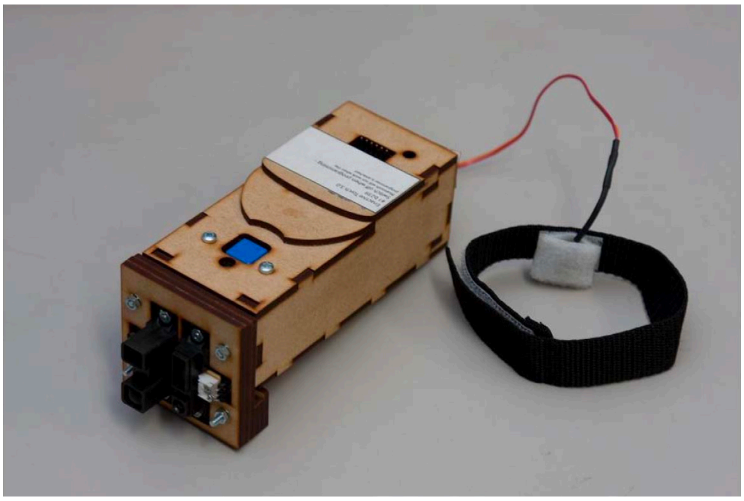


Fig. 9 - The eactive torch prototype, with the device on the left and the haptic actuator band on the right (Froese et al. 2012)

For their study, they made 22 participants navigate a labyrinth using the Enactive Torch and without the help of normal vision. The task proved to be somewhat challenging, but overall participants performed well (Fig. 10).

In the final results of their study, though, the findings were that, to use the Enactive Torch, participants had to deliberately think about the haptic feedback they were receiving and in how to use the Torch in order to navigate the maze. This experience is more akin to what a cognitivist interface is than an enactive one. It remains to be seen if these effects could be overcome in time with enough experience, meaning that interfaces can indeed become more "transparent" through time.

Fig. 10 - A participant finds his way through the maze with the enactive torch (Froese et al. 2012)

Wearable haptics for social walking

Although this project is not aimed towards embodied interaction, Baldi et al. designed a device that detects the walking rate of a user and then sends it to another to allow social walking (2020). The aim of the device is to allow people to feel a partner while they walk through the internet.

Other projects have approached this, like Mueller et al.'s system that allowed people to jog at a distance using audio cues (2014), or other past projects had used VTS to indicate cadence when running and walking, but the combination of using haptics for mediated social walking and presence is unique.

The audio channel is important for awareness of the surroundings, so blocking it for something like walking could be dangerous. Moreover, VTS are demonstrated to be a suitable way to indicate social and virtual presence in mediated interaction, showing that haptic feedback reinforces the impression that the other is there (Sallnäs, 2010).

The device they designed had a pair of anklets which transmitted the VTS and extracted the gait cadence to a smartphone application to link two participants (Fig. 11). The ankles are a convenient area of the body to which attach haptic actuators, as they are sensitive to vibrotactile stimuli (Gemperle et al, 2003). They then used short vibrations to signify the cadence of the other person.

Fig. 11 - The anklets prototype (Baldi et al.)

To test the concept, they used a four stage process: First, participants were asked to match their gait with a constant artificial reference; second, they had to follow an artificial leader that updated its cadence every 30 seconds; third, they were asked to follow a human leader and adapt to the perceived gait cadence; and finally, they did the social peer-to-peer walking experiment.

In human social walking with two or more people, adjusting to the pace of the group is an implicit rule and there are no specific roles. The final phase had both participants send their gait cadence to the other, and were asked to walk comfortably and adapt to each other's cadence. Participants had to "negotiate" what a comfortable pace was (Fig. 12).

The system proved to be effective in achieving its goal, participants aligned their gait on a common rhythm which was closer to the mean of their comfortable cadence, this synchronisation was perceived as satisfying. The responses to a post-experiment questionnaire also showed that people did get to feel the presence of their partner during the interaction.

Fig. 12 - Two participants in the last stage of the testing (Baldi et al.)

These two projects build on designing an interface that jumps outside the principles of visual interfaces to allow people to interact with the world and with each other. Both of them have different reasons for it, one of them aims to create an interface for augmented sense-making, the other to create a virtual presence for social walking.

The use of haptic vibrations as the main information output to the user is another thing that they have in common. Interest in interfaces based in conveying information through what is called "haptic display" is growing. In the next chapter, we will be focusing on the sense of touch and how haptic vibrations fit in this new landscape of digital interaction design.

2.2. Touch, an Unexploited Sense

Haptics comes from the greek word haptikos, which means "able to grasp or perceive". The haptic sense helps in a myriad of different ways: knowing when it is hot outside, avoiding tripping over your own legs when you walk or applying the adequate force to grab an egg.

2.2.1. The Haptic Sense

The haptic sense has two components to it: first, the somatosensory system, your skin and its receptors; and second, our kinesthetic sense, which is the sense that is aware of the position of our limbs in space. The combination of these two parts gives us our haptic sense, which we could define as "active touch" (Fig. 13).

Imagine holding a cup of hot coffee. The weight, the position, orientation and movement to successfully drink from it, even in complete darkness, are perceived through the kinesthetic sense. The texture of the ceramic, the force applied to avoid it slipping, the location of the handle on your fingers and the temperature of the coffee inside come from your tactile perception (Müller, 2020)

For a bit more of a technical definition human haptic perception is synthesised from tactile and proprioceptive senses. Tactile perception relies on multiple sensory organs in the skin, each meant to detect different kinds of touch. For instance, Merkel disks detect pressure and fine details, Meissner corpuscles detect fast and light sensations, Ruffini endings detect stretch and Pacinian corpuscles, vibration (Choi and Kuchenbecker, 2013). Proprioreception, is synthesised from other sensors, like the muscle spindle and golgitendon organs, combined with the sense of vision, to detect the location of our limbs (Kandel et al., 2000). We use these two senses to learn about the world that surrounds us in active exploration.

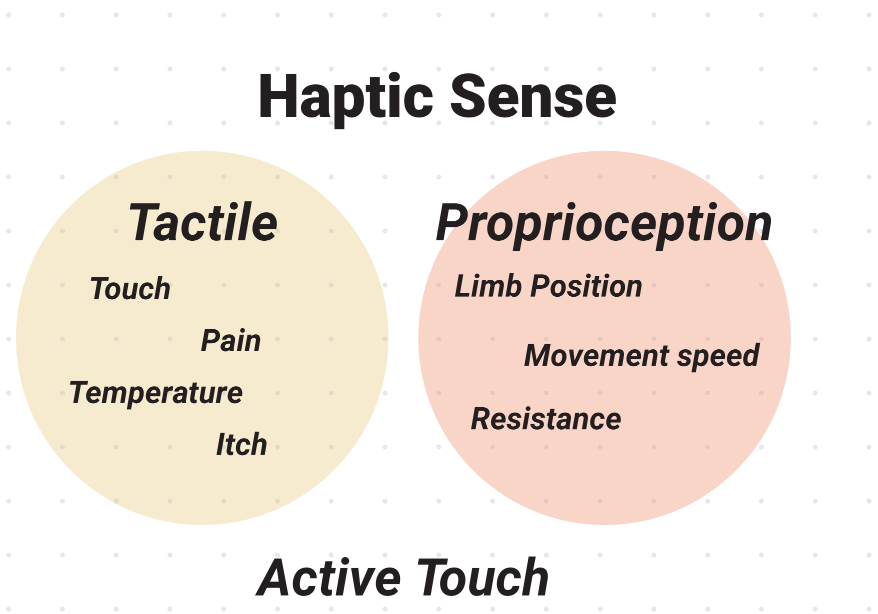


Fig. 13 - The two parts of the haptic sense

The field of haptics is a broad field of research and knowledge. Only within the somatosensory system, there are, allegedly, four kinds of inputs: "touch", itch, pain and temperature. There may be a fifth channel that senses affective touch (Jones, 2018).

The combination of these channels already makes the amount of information from the skin incredibly nuanced. When they work in conjunction, these receptors allow us to know what we are touching and what is touching us, and how.

2.2.2. Social Touch

Having all this input to play with, touch is a big part of human interaction. In physical and emotional well-being, for instance, touch is regarded as crucial for human development, to the point where infants that are deprived of touch can experience negative consequences on their overall well-being later in life (McLean, 2003).

It has been found that holding hands with a partner, rather than an object, results in lower pain rating (Master et al., 2009). It can also change people's behaviour in a phenomenon called Midas Touch, making people help, accept recommendations and even give bigger tips (Kleinke, 1977; Guéguen & Jacob., 2005; Guéguen et al., 2007). Even the touch of a doctor or a nurse (complete strangers) on the shoulder lowers heartbeat in patients in a hospital (Drescher et al., 1980).

There is still a lot to understand from this modality of communication though, with all kinds of different experiments to prove it. For instance, the social touch hypothesis states that some specific mechanoreceptors called C Tactile afferents (CTs) are especially involved in the sensing of social and affective touch (Morrison et al. 2010).

Later, another study published using tactile vibrations, a kind of stimulus that is not supposed to activate those CT receptors (Björnsdotter et al., 2009), and the results say that those receptors do not fully explain social touch, or mediated social touch (Huisman et al., 2016).

Social touch is something that science is starting to understand, and that can have big implications on how we understand social interaction and the effects of deprivation of touch, especially in times like during the ongoing COVID 19 pandemic.

2.2.3. Haptic Vibrations

Haptics, until around 30 years, was rigorously under a scientific and analytical rule. Engineers entered the picture and started to create a space for themselves, making it a more multidisciplinary field. Since then, there has been a dramatic increase in the amount of work published on the field, and a healthy and active community has gathered behind it providing great momentum to its growth (Moussette, 2012).

> *"A quarter century ago, haptics research was essentially the province of behavioural scientist and neuroscientists. The entry of engineers into the field transformed it into a truly interdisciplinary endeavour" (Kaltzky n.d., 2013, n.d.)*

However, the most advanced haptic technology and concepts are still far from hitting consumer level implementations, and the most advanced uses of these are primarily in laboratories for research (Moussette, 2012). Efforts, like Moussette's PhD *Simple Haptics* or Müller's *hapticlabs.io* toolkit (2020), are trying to help haptics grow out of those laboratories into engineering and design faculties to study future implementations and the formation of new professionals.

The main reason behind this is the increase of the presence of digital interactions and interfaces in everyday life. Each of them requires our visual and/or our acoustic senses to interact with it, both of them crucial for navigating the world. Overloading them means compromising the ability to perceive our surroundings, which is not ideal.

The haptic sense on the other hand, is a peripheral input which constantly operates in the background (Jones, 2018). The technology that uses this sense to send information is called *haptic display*, which leverages the different modalities with which the haptic sense works to display different information. These displays, as mentioned, are still an experimental technology that is more present in research labs, due to their cost and complexity.

But the increased interest is starting to show, as companies like Apple, with their Taptic Engine, or Sony, with their new generation PS5 DualSense controllers are bringing more advanced haptic technologies to the table (Fig. 14). These products are pushing beyond the boundaries of the traditional buzzing vibrations which has remained unchanged since the 90's, to provide more advanced feedback and allow users to feel complex information and better immerse in the action of the game.

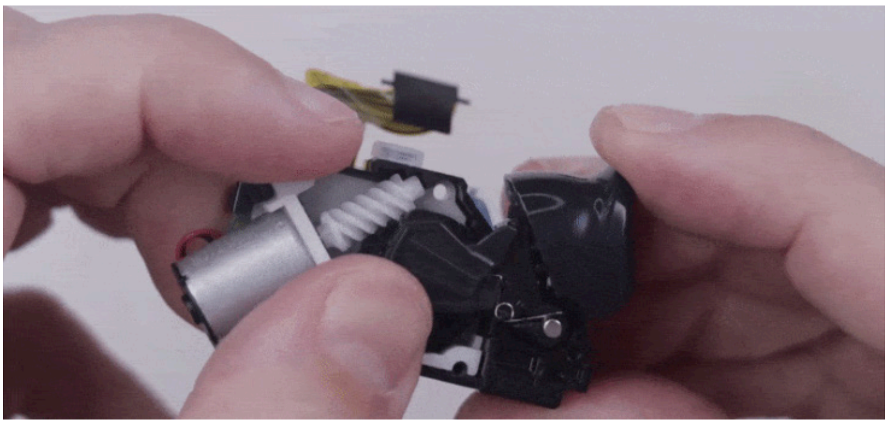


Fig. 14 - Adaptative triggers in the PS5 DualSense Controller (TronicsFix)

The rise of VR technologies is also pushing the envelope of haptic technologies, with the necessity of creating more immersive experiences in new virtual environments. Virtual reality calls for more embodied interactions for the user, and that means more complex feedback is necessary. For reference, see projects like Omni One by Omni, Nova by SenseGlove or the TacSuit by bHaptics (Omni; SenseGlove; bHaptics).

To add to this , from my personal take, shared with other researchers in the TU Delft's faculty of Industrial Design Engineering community, the lack of interest of digital designers towards haptics, specially haptic vibrotactile stimuli, has not been as explored partially due to the lack of insight on the aesthetics of tactile vibrations. Usually tactile vibrations are disregarded as "annoying" or "one-dimensional" (Hasegawa et al., 2019).

Even when interfaces allow better usage of the motor capabilities of the human body, like the Nintendo Wii and Switch controllers or Microsoft Kinect, the output has never really been the skin, or the haptic sense.

However, in recent years, even within the research community at the TU Delft, several different studies have been conducted in the aesthetic perception of vibrations, in projects like van der Madden et al's *Feel the Vibe* (2020) (Fig. 15), Shor et al's *Resonance Pod* (2021) and my own research *Sweet Sensations* (see section 2.2.4). This showcases an interest on the field of design in the possibilities of our skin as an output for digital devices.

2.2.4. Sweet Sensations - Aesthetics of Tactile Vibrations

The first place where to look for similarities for the perception of haptic vibrations is audio. The aesthetics of audio, although not as extensive as visuals, have been explored in the past.

Studies like Vitz' (1972) already explored the preference of individual frequencies by individuals. 16 subjects were presented with combinations of different sine waves of 60, 110, 210, 400, 750, 1410, 2660 and 5000 Hz. He found consistency on the preferences of the subjects in the middle of the spectrum (400 and 750 Hz), even though there was big individual variability.

Fig. 15 - Feel the Vibe Chair (van der Madden et al.)

Inspired by these kinds of experiments, a research project was conducted (by me) in the aesthetic perception of different frequencies and combinations of those in a vibrotactile format, called *Sweet Sensations*. The aim of the project was to understand if there is a common aesthetic perception of certain vibrotactile frequencies and see how these principles could be applied to design better vibrations.

To do so, using a staircase approach, pure tones from 20 to 500 Hz and combinations of different frequencies with the base frequencies 40 and 180 Hz were tested, playing them to 25 participants through LoFelt L5 high precision voice coil actuators (see section 3.3.2 for detail on the actuators). To give it more depth, consonant and dissonant frequency combinations were played, as these phenomena have been extensively studied in audio (see Mcdermott 2012 for a review), but not really on tactile vibrations.

These frequencies were rated on aesthetic measures of pleasantness, interestingness and arousal by the participants sensing them.

The actuators were located on the inner side of the wrist, a place that is remarkably sensitive to the changes in tactile vibrations (Fig. 16), which helped participants to be able to perceive the differences between the stimuli on the staircase (Karuei et al., 2011).

The results of the experiment aligned with past research by Berlyne (1970) on the perception of audio tones. He found that the perception of stimuli adapted accurately to the Wundt curve (Fig. 17). This curve illustrates that as the arousal potential of a stimulus increases from low to medium levels, they are perceived as pleasant, but when reaching higher levels, the stimulus can become unpleasant and even painful.

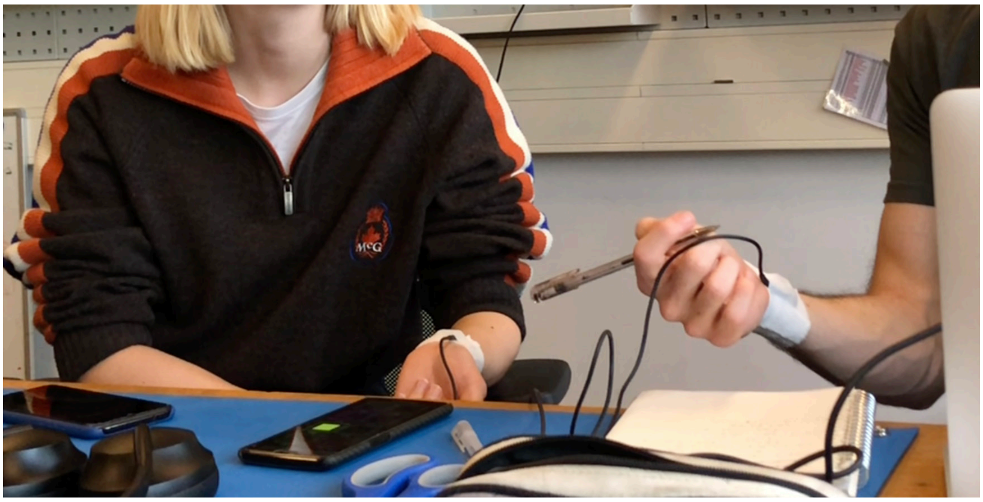


Fig. 16 - A participants senses the vibrations in their wrist

The resulting curve resulting from this experiment did indeed have an inverted U-shape when relating the levels of perceived arousal and pleasantness (Fig. 18). There are frequencies that are perceived as more pleasant than others consistently, and they seem to follow the pattern Berlyne described in his research.

This means that although there is a high rate of individual variability within the perception of vibration patterns on the skin, there are certain parameters that can be used in order to design more aesthetically pleasant vibrations in future. And this was the next step to be taken, to apply this knowledge to interpersonal communication.

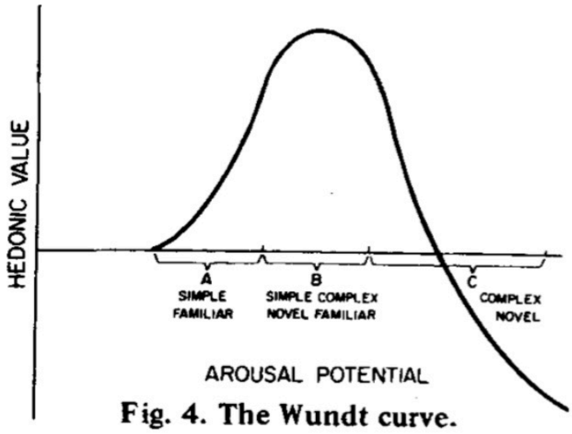


Fig. 17 - The wundt curve (Berlyne, 1960)

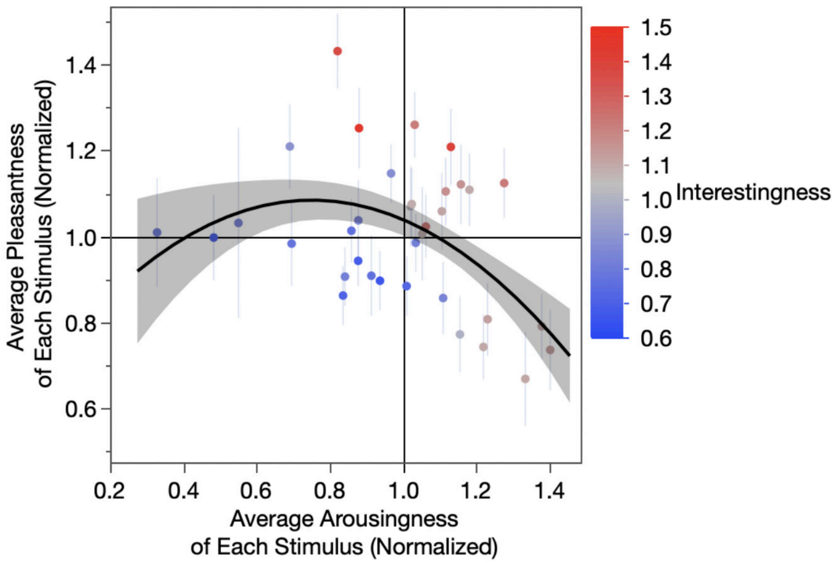


Fig. 18 - The resulting curve from the staircase experiment

2.2.5. Communication through Haptic Vibrations

One of the potential applications of haptic technology in modern interfaces is the possibility it has to be introduced in the process of interpersonal communication. As mentioned earlier, current digital interaction does a poor job replicating the multi-sensory nature of human experience, and this expands to interpersonal communication.

Using haptics for interpersonal communication brings several challenges to the table. There have been projects in the past around the potential of haptic vibrations in communication, from ideas of implementing vibration patterns in mobile messenger apps, to prototypes that use arrays of actuators to create different effects.

Feel Messenger

Feel Messenger is one example of the first kind of application (Israr et al., 2015), where they developed an application that allowed people to customise their own tactile vibration patterns for implementation in a messaging app where the haptic vibrations would be sent as messages to increase expressivity.

To do so, they developed what they called a Haptic Vocabulary in which different effects could be set to create the patterns. These patterns were divided into three different types: Feel Effects, Physical Effects and Symbolic Effects (Fig. 19). Feel Messenger included a library of predefined patterns and an editor for participants to create their own combinations.

In their preliminary study, the research team developed a mockup application which allowed people to feel the different effects and to see how they were implemented in a hypothetical conversation. The overall user ratings after the experience were positive, and remark that the inclusion of personalised haptic messages will be an stimulating and exciting addition to the current networking tools available.

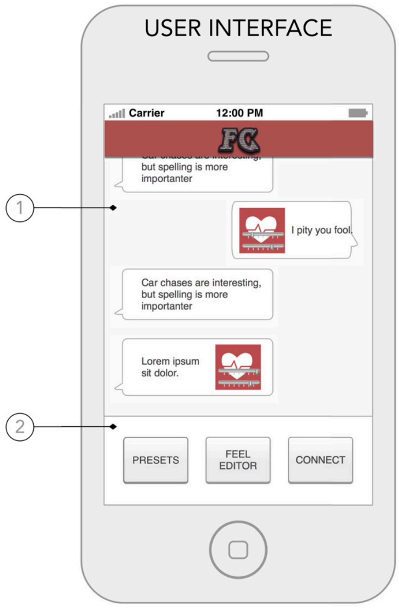


Fig. 19 - Feel Messenger interface (Israr, 2015)

TaSST

For a more complex and capable solution, there is TaSST, or the Tactile Sleeve for Social Touch. This device, developed by Huisman et al. (2013), is a sleeve with a grid of haptic actuators and pressure sensors designed to allow two people to synchronously engage in mediated social touch by touching their own forearm

The array of actuators and sensors in this case allows to accurately simulate ways that people use to touch each other in social situations, such as laying the hand in the forearm, to stroking movements. The researchers recorded some movements on the sleeves that they played to participants, and then asked them to recreate them (Fig. 20).

From their experimentation, participants could successfully recreate touches such as pressing and squeezing, and that simple touches were also understood, although more difficult to recreate. Finally, the interface was not as suitable for complex touches.

This same device was used to simulate stroking sensations and assess the aesthetic qualities of simulated affective touch (Huisman et al, 2016).

In both cases, they demonstrated that although it is not the same as being touched by an actual person, it is possible to make accurate and understandable representations of social touch and that the array of vibration actuators can generate an aesthetically pleasant experience.

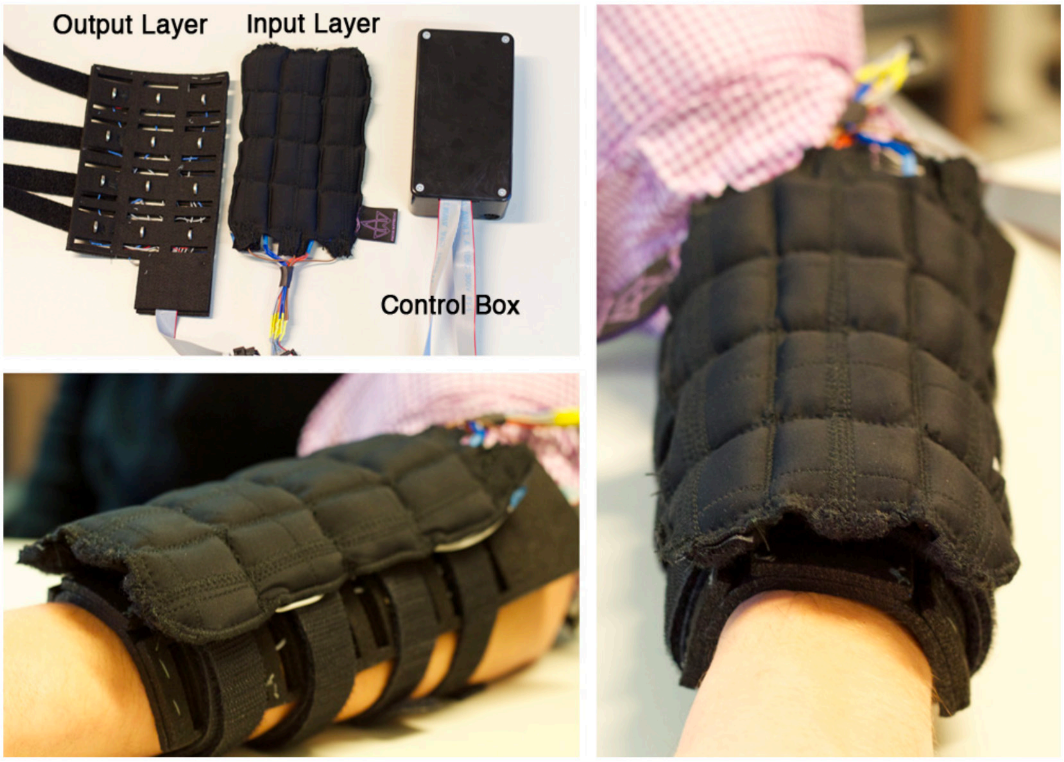


Fig. 20 - TaSST prototype (Husiman et al. 2013)

Evocative vibrotactile stimuli

Using a Haptuator Mk. II, Macdonald et al. conducted a research on the use of VTS evocative of the real world to create emotionally resonant vibrotactile stimuli (2020). Previous research on vibrotactile affective touch had been focused around short and abstract waveforms (Hasegawa et al., 2019) or tactons (Brewster & Brown, 2004; Yoo et al., 2015). Research on the effects of VTS that were designed to mimic sensations on the real world without other modalities.

For their research they conducted two studies. The first focused on the effects of duration on the affective properties of VTS, and the second on the emotional resonance of VTS. Using a flask cap filled with soft foam, they created a hand rest device, they played the different tactons, both the abstract and evocative of real-world sensation (Fig. 21). They also isolated participants from possible sounds of the actuator using brown noise playing headphones.

They found no significant main effect in the length of the stimuli, but the interesting outcome comes from the second study. To analyse the emotional resonance of VTS, what they did was create vibrations stimuli evocative or real-world sensations and played them to participants. Participants managed to recognise some of the stimuli, but the affective response relied on the personal connection of the participant with said stimulus.

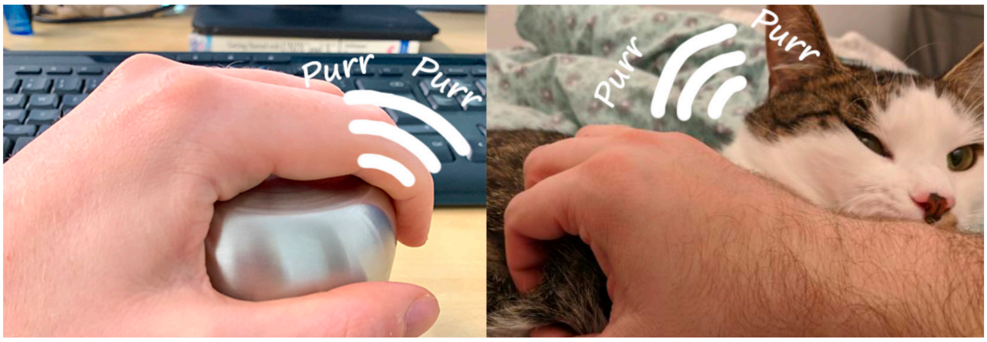


Fig. 21 - The device used on the research, playing a stimulus evocative of a cat purr

The emotional reaction when a stimulus was recognised by multiple people was not consistent. The heartbeat related vibration, for instance, found both people relating it with unpleasant imagery (negative) and a soothing rhythm (positive). Still, the affective range of the vibrations was expanded by the evocative sensations successfully, that is, if the participant made sense of it.

For more projects related to social touch, Huisman himself has a comprehensive survey on the usage of haptic technology, not reduced to tactile vibrations (Huisman, 2017). In his conclusions he outlines the possibilities of social touch technology, where he outlines that the effects of it are not because of the similarity of the input to actual human touch, but to the attribution of this touch to another person.

> *"It is important that the recipient of touch is aware of the fact that the felt haptic sensation originates from another social actor. Only when a haptic sensation is attributed to another social actor can it serve as a social signal, and only when a haptic sensation is considered a social signal does it have the potential to produce effects similar to social touch." (Husiman, 2017, pp. 12).*

In the same document, Huisman points out various possible research questions on the future of haptic communication research. First, he discusses the necessity of a structural investigation of mediated social touch, both top-down (attribution) and bottom-up (somatosensory processing).

Second, the necessity to research to what extent the physical properties of the haptic stimuli matter when simulating touch through social touch technology. One of the most solid conclusions of his entire survey is that even haptic stimuli that offer a very limited part of human touch can trigger the desired effects.

Therefore, there is a big space to approach the research of vibrotactile stimuli for communication, and a lot of different questions to be answered.

2.2.6. Enabling Emotional Mediated Interaction

Having researched the current context on interfaces for mediated social interaction and having better understanding of the principles outlined by previous research projects, the next step was to formulate a goal for the research ahead. The potential of the mix of the principles of the enactive approach and haptic vibrations to create an emotional, engaging and rich interaction was promising and unique.

Considering all this, the goal of this research is defined as follows:

To design an interaction that allowed participants to interact through haptic vibration technology and elicited an emotional response.

To guide the research, principles and theories like the enactive approach gave some clues on the kind of interaction to look for, but many directions remained open to explore. Therefore, to narrow the exploration, the following research questions were formulated:

- Can we create an ***augmented*** and ***participatory sense-making*** mixed interaction haptics?
- How can we design ***vibrations and waveforms for an interaction*** focused on eliciting an emotional response?
- How can we design a ***prototype*** that allows such an interaction that triggers the desired results?

The different experiments and prototyped interactions would be constructed with their own set of questions, goals and interaction visions, but they were designed to respond to these three questions. The presented questions spin around social interaction and participants interacting with technology and interfaces, and to acquire it, it made sense to get participants interacting quickly.

3. Exploring Communication through Haptics

3.1. Experimental Approach

At the start of this project, *Sweet Sensations* research project (see section 2.2.4) had already been completed, which could be related to what Huisman (2017) refers to as the bottom-up approach, having conducted a survey about the aesthetic perception of vibrotactile stimuli, so the perception of different VTS was already understood

The approach to the exploration of the field was inspired by one of the projects that Moussette presents in his thesis, in a process which he calls haptic sketching (Moussette, 2012). In one of his seminars, Moussette received feedback in which participants criticised his approach of sketching as the primary means to engage with the space, without thoroughly researching the field and framing the domain of study.

His response to the critique was that the results that he had obtained would most likely change in a similar process, regardless if the researcher would have been him or another person. This did not mean that the outcomes were random, but rather that they came from the process of "conversations with the design material and the design situation at hand" (Moussette, 2012, pp. 127).

These kinds of activities, related to approaches like research through design in which the act of designing is considered a way of creating knowledge and the resulting artifacts the carriers of said knowledge (Giaccardi & Stappers, 2017), build skills and awareness on the design matter at hand, which was what was necessary to design a haptic interaction like the one that this project was aiming for.

In this case, the experimental knowledge was necessary to advance the project in an iterative way in order to explore the space quickly. The goals of the project also called to design an interaction, and to do so, practical knowledge from observing interactions seemed to be the best option.

The experimentation runs on this project were different from Moussette's, as the approach to the experiments was a bit more scientific in this case. A certain amount of consistency was needed through the groups in order to get the insight that would respond to the research questions, therefore the cycles were not as immediate.

The first experiment, expression through haptic vibrations, consisted on getting two participants together to co-create vibrations based on a trigger set prepared prior to the session. The second consisted in a game of haptic charades, where participants had to guess what the other one was trying to transmit to them through vibrations.

3.1.1. Interfaces for Haptic Interaction

There are several challenges in the way of haptic experience design (HaXD), from the multi-sensory nature of the interactions, to the technical difficulty due to the youth of the field (Schneider et al. 2017). One of the biggest challenges which had to be addressed during the current project was creating test setups that would allow participants to control and experience haptic vibrations.

Demos with haptic technology are hard to manage due to the proprietary and highly specialised hardware, the complexity of the software and the need to be present in order to experience it. Each experiment would have its own set of requirements, and each waveform needed a specialised interface to control it.

Other projects in the past had already developed a set of different software and hardware tools to design interfaces and allow participants to manipulate vibrations. Those tools were used in *Sweet Sensations*, where the resulting interfaces were called *Playgrounds*.

They were still visual interfaces and were far from what was envisioned to be the result of the project, but proved to be useful for the first stages of the project, where the exploration of the interaction was what was prioritised over the interface (Fig. 22). Designing the *Playgrounds* was an important part of the testing process and showed the complexity of designing for haptics nowadays.

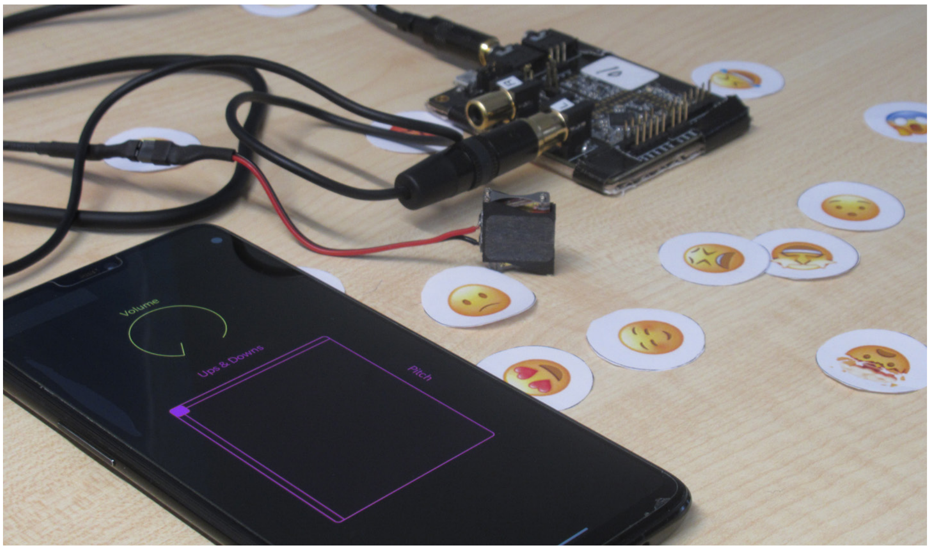


Fig. 22 - Interface designed for the 2nd experiment of this project

3.2. Expression with Haptic Vibrations

Experiment Goal

To find out how people will interact around vibrations

To gather data on how people express different triggers

Research Questions

Will participants in the same group agree on how certain triggers feel?

Will there be consistency on how different groups communicate certain triggers?

Are there kinds of triggers that are better suited to be perceived or communicated through haptics?

Interaction Vision

Creating vibrations should feel like...

To get the experimentation cycle started, the first experiment was meant to be a simple test of concept: can we get two people to agree on how certain triggers should feel in a VTS form? What this interaction would allow is twofold, first is to observe people interacting with vibrations, and second, to find out if there is consistency in how different groups express the provided triggers.

Getting people to understand what the others are doing is an important part of social interaction, and if participants could not engage in participatory sense-making, it would not be possible to create an interaction based on VTS. It was already known from previous experimentation that there is individual variability in how people perceive certain cues (Macdonald et al., 2020) or in the aesthetic perception of VTS, but seeing if participants could figure out together the meaning of vibrations could be a promising start.

It was also the first time creating waveforms for social interaction, and the first iteration of the waveform followed a conventional vibration "pulse". Some of the parameters could be changed to manipulate how the vibration felt (Fig. 23). Making it conventional and simple was a way of getting participants comfortable for the experiment as soon as possible.

A total of 8 participants participated in the study, of which 4 were female, all of them students at the TU Delft. The ages ranged from 24 to 27 years old. Only one of them had previous experience with VTS research or devices apart from basic interactions like phone vibrations and video game controllers. 3 of the couples were friends, the remaining one was formed by complete strangers.

Fig. 23 - Interface 1 used to modify the pulses

3.2.1. Allowing Participants to Co-Create Pulses

As participants were going to be representing cues of different kinds, which have a self-contained meaning, the best way to create those representations was using vibrations that were also self-contained, meaning that they were vibration pulses, with a beginning and an end.

These kinds of stimuli are called *envelopes*, which can have different "shapes" (Fig. 25), so they are flexible and allow participants to freely manipulate how vibrations feel. In this case, the envelopes were designed to be simple and intuitive, with three parts: attack or fade-in, sustain period, and release or fade-out (ASR). Participants were allowed to manipulate the length of each section in order to create smoother or sudden pulses of different lengths, depending on the cue they were trying to represent.

The other parameters that participants were allowed to change were the intensity and the pitch of the vibration. These two parameters have been closely related to the valence and the arousal levels of stimuli in my past research *Sweet Sensations*. To do so, participants could change the frequency or pitch and the amplitude or volume of the vibration.

3.2.2. System Overview

The experiment system was comprised of three elements:

- A pair of Android based smartphones running TouchOSC
- A pair of LoFelt L5 voice coil actuators
- A laptop to transform the smartphone signals into VTS

Smartphones running TouchOSC

To act as the interface, a pair of smartphones (one for each user) were running TouchOSC, an application that allows the creation of modular interfaces in devices with touchscreens and uses the Open Sound Control (OSC) protocol. The OSC protocol serves to network synthesisers, computers and other multimedia devices to control different aspects of musical performance (Wright & Freed, 1997).

These interfaces were designed and created for this experiment, and are one example of the aforementioned Playgrounds. Touch OSC allows one to have different virtual elements in an interface, like sliders, rotary switches or buttons and output those values into a OSC signal that any device listening to it could use as inputs (Fig. 24)

As this experiment's goal was to have participants creating haptic vibrations together based on the principles of jamming, the interfaces available to manipulate and create the vibrations were different for each participant, and swapped mid experiment. The interface on the left had control over the shape of the envelope, with controls for the fade-in, sustain and fade-out phases and the volume of the vibrations. The one on the right controlled the frequency of the vibration, plus also had a play button to play the envelope and see how it felt.

LoFelt L5 actuators

The LoFelt L5 voice coil actuators are high-precision actuators that can deliver strong and high definition haptics. It offers more power and better definition over traditional ERM (Eccentric Rotary Mass) and LRA (Linear Resonant Actuator) motors and other technologies like piezo or EAP (Electro-Active Polymer). The actuators can be driven using audio signals, being able to operate for prolonged periods of time without drops in performance.

Their technical features make them very convenient, for their integration is fairly simple. They offer good response of minimum 1G with their 30g mass in the key haptic sensitivity frequencies, from 45 to 250Hz, but its range is wider than that, from 35 Hz to 1 KHz. They are almost completely silent compared to other actuators, and they are quite compact, with a 6.2mm height package (LoFelt, 2019).

Computers and software

In order to transform the inputs in vibrations, a MacBook Pro computer running Processing, a Java based software, captured the signals sent through the OSC protocol and transformed them into signals usable by the synthesiser. This step was necessary and gives flexibility in case of necessity to tweak the signal. It also allowed us to record what the participants were doing in real time.

The different elements in the TouchOSC interface were mapped to certain elements of the waveforms in Processing and then sent to the synthesisers. The synthesisers were hosted on the local server using SuperCollider, a software and programming language that allows one to code synthesisers for audio output in real time. Those vibrations were then outputted to the actuators to create vibrations.

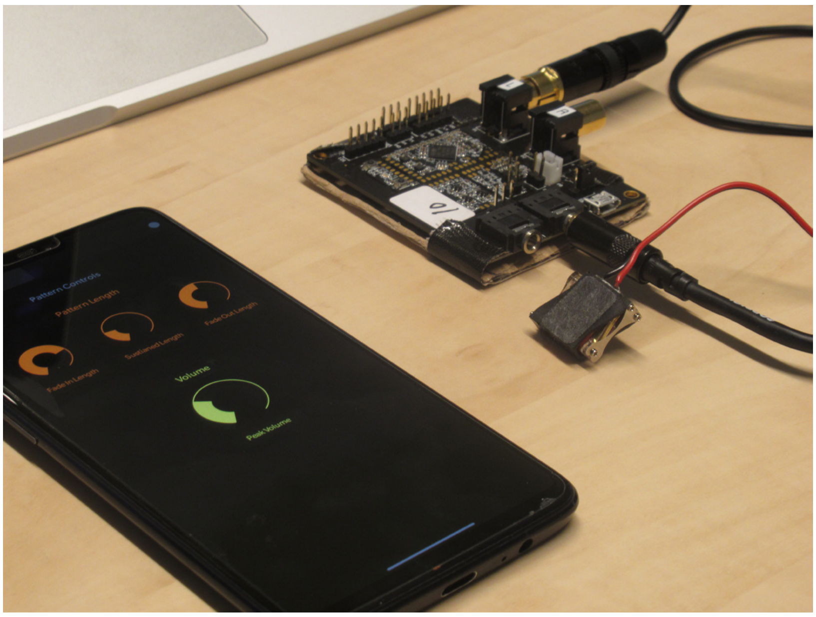


Fig. 24 - TouchOSC Interface and LoFelt Actuator

3.2.3. Experimental Methodology

The purpose of defining an interaction vision was to extract certain elements from that vision in order to define aspects of the experiment. In this case, jamming is a fun activity where different members of a band improvise and together create a totally unique music piece. It is a playful, coordinated and explorative activity, and those were the factors that were taken from that vision to create the final experiment.

The experiment was presented to participants as a fun activity, where the vibrations that they created were creative contributions to the project, as I did not know either how different cues would feel in a haptic vibration format. This relieved the pressure of performing and allowed participants to be freer to explore and talk with each other.

3.2.4. Participant Interaction

The two participants sat down at a table together, where the experiment was going to be conducted. On the table was a computer that would be transmitting the haptic vibrations to the L5 actuators, which were strapped to the inner part of the non-dominant wrist of each participant using cohesive bandages. The wrist is one of the most sensitive areas to haptic vibrations (Karuei et al., 2011).

Afterwards, they were given the interfaces that would allow them to tweak and compose the vibrations (Fig. 25). After an explanation on how the interface worked, participants could have up to 2 minutes to experiment with the interface and the vibrations. Both participants felt the same stimuli at the same time.

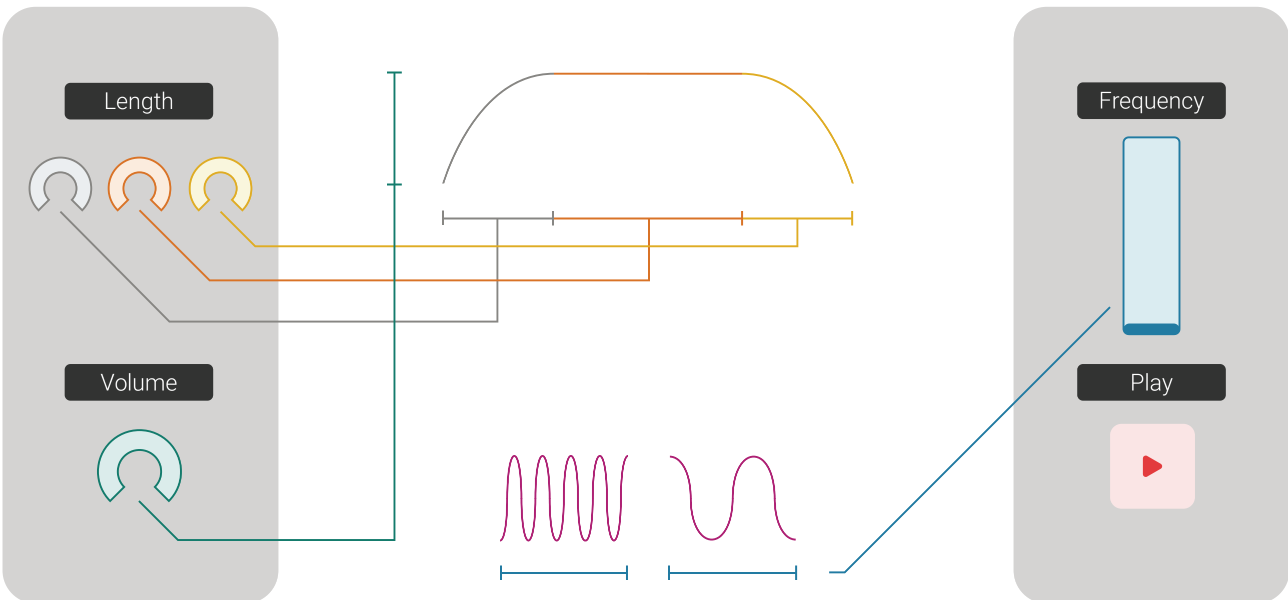
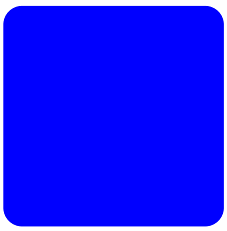
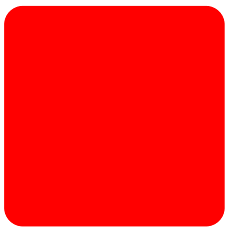


Fig. 25 - Representation of the interfaces and how they affect the envelope (left) and waveform (right)

After the adaptation time, participants were presented with the different triggers to make into vibrations in the same order for all groups. They were asked to discuss the different triggers, to describe the different vibrations they made and the reasons why or why not they fitted the trigger. The process was based on iteration; one of the participants could play the vibrations with a play button on the interface for both of them to feel it. This allowed partcipants and not the researcher to be in control of the vibration and experience as many times as they wanted to adjust it to their liking.

The experiment had two rounds and participants switched interfaces between those. After the test, participants were presented with a form (see Appendix 2) where they rated the experience and gave qualitative feedback about the experiment anonymously. Some of them completed it in the same room right after the test, but some others did not have the time to do so, so they were allowed to fill the form later.

Table of Triggers

Set 1	***Set 2***	***Set 3***
	Emotion	
Affection	Anger	Disgust
	Texture	
Rough	Smooth	Fragile
	Gesture	
Playful Push	Finger Snap	Elbow Bump
	Image	
		
	Color	
		

3.2.5. Results

To understand whether there were consistencies in how different groups of people would characterize different stimuli and whether particular types of stimuli were more consistent than others. To do so, first, the means were visualized to see whether there were visible differences in the stimuli (Fig. 27). Next, a series of regressions were ran to predict the parameters based on the trigger type (Fig. 28).

In each component of the vibration (e.g., ASR, amplitude, frequency), emotional triggers were more predictable than other triggers. With the exception of amplitude and sustain, the co-created vibration components predicted the emotional trigger. In contrast, gestures were predicted only by sustain and attack. This suggests that emotional communication through vibrations is a promising approach.

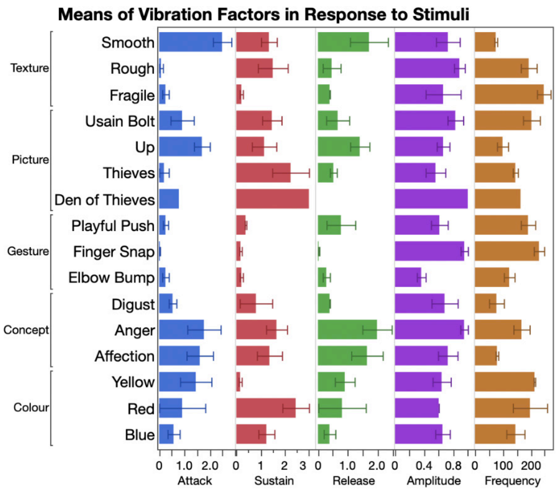


Fig. 27 - Results of the different parameters depending on the trigger

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.9158788	0.129739	7.06	<.0001*
Trigger type[Colour]	0.0341212	0.262811	0.13	0.8972
Trigger type[Concept]	0.5774545	0.254395	2.27	0.0274*
Trigger type[Gesture]	-0.742545	0.254395	-2.92	0.0052*
Trigger type[Picture]	0.0632121	0.262811	0.24	0.8109

Attack

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.1216848	0.119307	9.40	<.0001*
Trigger type[Colour]	-0.056412	0.24168	-0.23	0.8164
Trigger type[Concept]	0.2731485	0.23394	1.17	0.2483
Trigger type[Gesture]	-0.841185	0.23394	-3.60	0.0007*
Trigger type[Picture]	0.5363152	0.24168	2.22	0.0309*

Sustain

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8672273	0.120114	7.22	<.0001*
Trigger type[Colour]	-0.219045	0.243315	-0.90	0.3721
Trigger type[Concept]	0.7061061	0.235523	3.00	0.0042*
Trigger type[Gesture]	-0.428061	0.235523	-1.82	0.0749
Trigger type[Picture]	-0.091773	0.243315	-0.38	0.7076

Release

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.7325303	0.032565	22.49	<.0001*
Trigger type[Colour]	-0.094348	0.065966	-1.43	0.1586
Trigger type[Concept]	0.0774697	0.063854	1.21	0.2305
Trigger type[Gesture]	-0.051697	0.063854	-0.81	0.4218
Trigger type[Picture]	0.0156515	0.065966	0.24	0.8134

Amplitude

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	161.18918	8.839368	18.24	<.0001*
Trigger type[Colour]	18.057182	17.90588	1.01	0.3179
Trigger type[Concept]	-46.11418	17.33244	-2.66	0.0103*
Trigger type[Gesture]	30.800818	17.33244	1.78	0.0814
Trigger type[Picture]	-1.090091	17.90588	-0.06	0.9517

Frequency

Fig. 28 - Regression analysis depending on the type of stimulus

The experience was rated quite highly by the participants, with an overall rating of the experience of 4.44 out of 5, with engaging (100%) and fun (88.9%) being the words most associated with the experiment in a multiple choice question. Participants were also asked if they got to really feel those sensations in the trigger set that they were supposed to be communicating, and the result showed that they strongly, with a 4.33 out of 5 being the average agreement with the statement (Fig. 29).

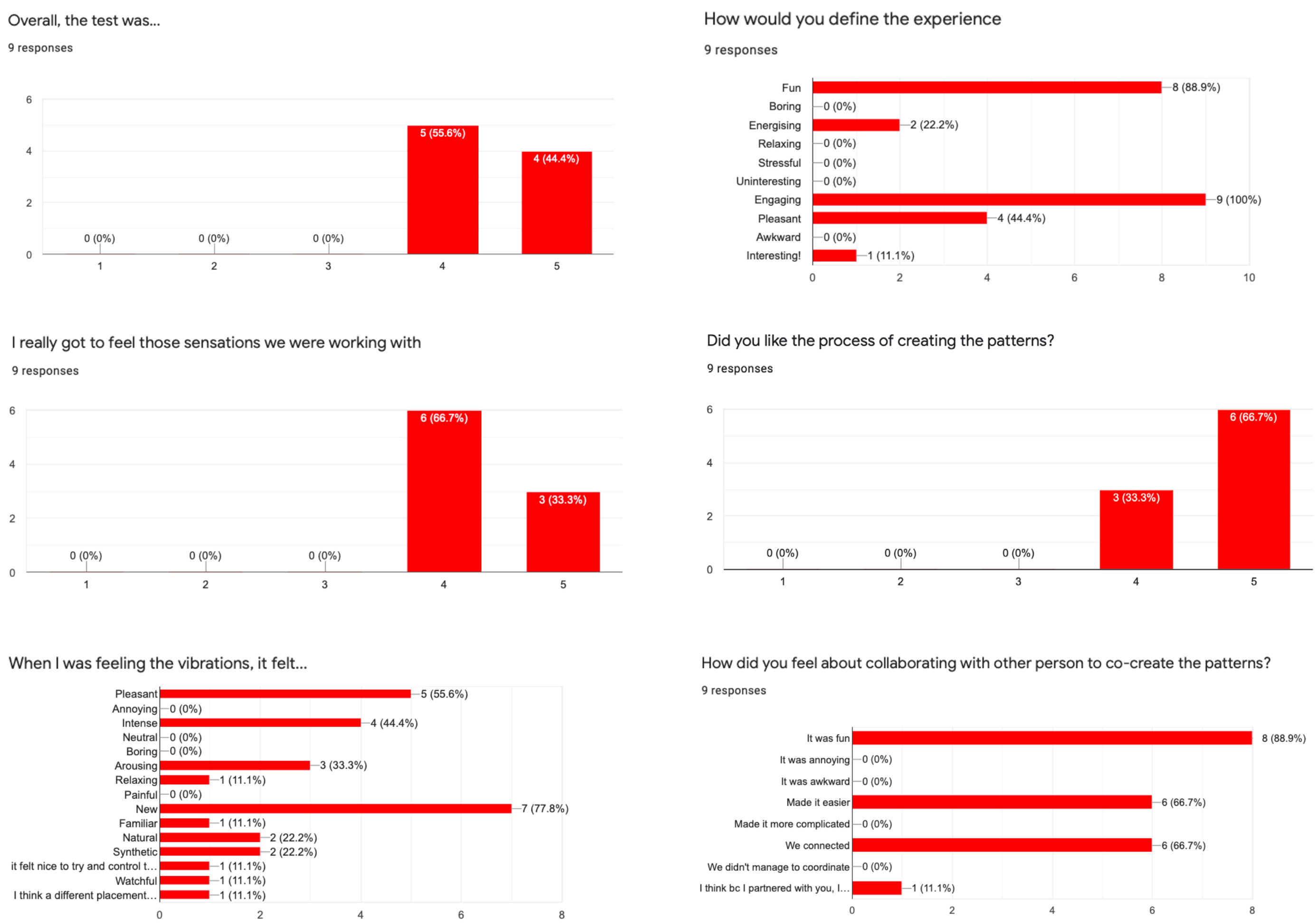


Fig. 29 - Responses to the post-test form of experiment 1

3.2.6. Conclusions

Participants got to feel the sensations on the trigger set

All couples managed to successfully get to an arrangement on how the different triggers ought to feel. Although some of the triggers were more difficult to express, all groups got to co-create all the pulses successfully. This means that indeed participants co-located that are allowed to discuss and co-create the pulses can agree on how certain cues should feel, at least in the format that was used in this case.

Not only that, but at the end of the test, when asked if the stimuli they had created felt like the triggers they had to represent, 3 of the participants strongly agreed with the statement, and 6 agreed. This means that they had successfully recreated the triggers in the forms of vibrations and that the vibrations could convincingly represent them.

If this is the case and people can agree on what they are feeling and create a common understanding, participatory sense-making could be possible through VTS. This aligns with the literature that was reviewed in the previous sections of the report (Macdonald et al. 2020; Huisman 2016).

Engaging and fun experience

As shown in the results section, participants did not only enjoy the interaction, but actually found it engaging and fun. From the literature that was reviewed, not many of the publications focused on the experience itself, but these numbers make it promising to design interactions that can be interesting, engaging and fun (Baldi et al., 2020; Froese et al., 2012).

The collaborative aspect of it also seemed to positively affect the interaction. The social aspect of it could make the adaptation to this novel kind of interaction and keep it interesting after the novelty factor dissolved. The only participant that expressed that the sensations were familiar still rated the experience with a 4 out of 5.

3.2.7. Next Steps

After having explored how participants interacted with vibrations and how effective some of the triggers were, the next step was to create an interaction that relied more on VTS to communicate. Still, the experience should remain social, or at least be conducted between at least two people.

3.3. Perceiving Emotions through a Haptic Link

Experiment Goal

Find out how people perceive and communicate emotion through haptic vibrations

See if contimuous vibration will better support interaction through haptics

Research Questions

Will people be able to communicate triggers through VTS?

How will the different features of the vibrations relate to different emotions?

Will vibrations be dialed consistently by participants for the different triggers?

Interaction Vision

Creating vibrations should feel like...

The next step in the research was to give the vibrations a central role in the proposed interaction: from interacting *with* vibrations to interacting *through* vibrations. Making this evolution was not easy. Interacting through vibrations required an interface and a type of vibration that could fit in the constant exchange that is human social interaction (de Jaegher & di Paolo, 2007).

Inspired by the game charades, where a participant has to guess the word that the other is trying to mimic without talking, we conceived the game "haptic charades", where one of the participants was in control of the waveform, while the other tried to guess which trigger the other participant is trying to convey.

As in the game charades, the sender was not able to talk, while the guesser could describe what they were interpreting out loud. This allowed both participants to interact through the vibration signal to understand each other.

The mechanics of the game charades not only helped us to outline the structure of the test, it also dictated the nature of the vibrations that were used during the experiment. When playing charades, the interaction is highly dynamic, with people continuously trying to guess what the person mimicking is trying to convey, and that person constantly adapting their performance to make the guessing easier.

For this case, the envelopes presented earlier did not cut it, they were not dynamic enough, and did not allow the characteristic feedback loop required to play the game to appear. In this case, a vibration that would play continuously and that reflected changes in real time was needed. To do so, the vibration was changed to a continuous stimulus and a more flexible interface that allowed participants to change different parameters in real time.

A new parameter was added to the stimulus, the incident waves. Incident waves interact with the main wave and compensate for it (Fig. 30), creating an up and down feeling on the amplitude of the frequency. Long incidents have long cycles (from 0.1 to 1 time per second) of ups and downs, while short incidents have shorter ones (from 1 to 30Hz, where the up and down is not perceivable anymore). They gave the sender a new parameter that added a new dimension to the expressivity of the wave.

A total of 7 sessions were conducted, which means that there were 14 participants in total, 7 of which were female. The ages ranged from 22 to 27 years old. 3 of the participants had participated in the previous experiment. 2 of the couples were friends, 4 were complete strangers and the last just knew each other but did not consider themselves to be close.

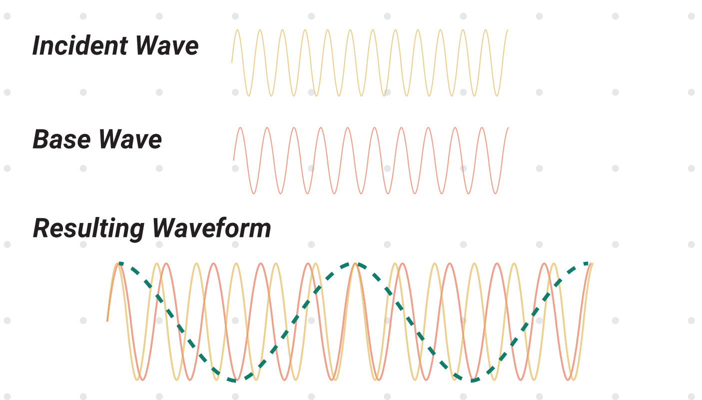


Fig. 30 - Incident Wave

3.3.1. System Overview

The experiment system was comprised of three elements:

- An android phone to serve as interface running TouchOSC
- A pair of LoFelt L5 voice coil actuators
- A laptop to transform the smartphone signals into VTS

Smartphone running TouchOSC

The foundation of the test interface, actuators and software in this experiment was the same as in the previous one (see section 3.3.2).

The interface changed significantly due to the nature of the interaction and the vibration that had to be controlled. The interface had to be adapted to a new, more interactive and dynamic interaction, and needed a new set of controls. Furthermore, the relevant parameters for the waveform had changed as well.

In this case, a tactile 2D pad could control the frequency and the incident wave with a single move (Fig. 31).

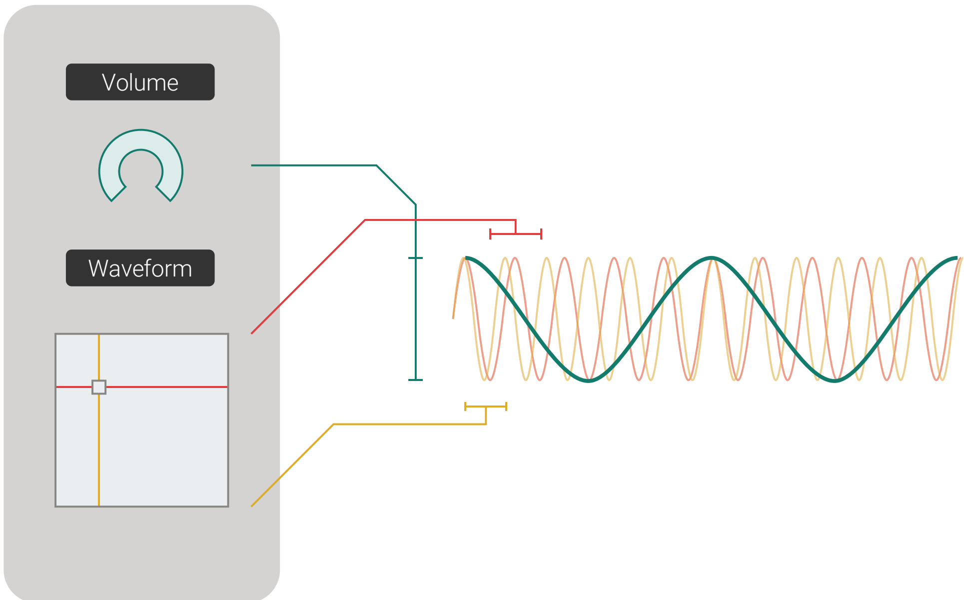


Fig. 31 - Representation of the interface and how it controlled the waveform

3.3.2. Experimental Methodology

The experiment was set up following what a charades game would be like. The triggers were printed in bits of paper and put inside paper cups so the sender at the time could pick one which then they would try to convey. The experiment was designed so each participant would be both sender and guesser twice.

To represent the different emotions, emojis were used. Emojis are a universal way of communicating and signifying emotions that have been used in the past in an emotional rating system, so they seemed as a good way to represent emotions for this experiment (Toet et al., 2018). The emojis were selected and grouped in pairs of high and low arousal variants of each emotion.

Table of Triggers

		High Arousal	*Low Arousal*
Set 1	Happiness	🤩	🙂
	Surprise	🤯	😯
Set 2	Sadness I	😫	😔
	Anger	😡	😒
Set 3	Fear	😱	😨
	Humour	🤣	😄
Set 4	Affection	😍	☺️
	Sadness II	😭	😁

3.3.3. Participant Interaction

This set of experiments were conducted in the Touch Lab at the TU Delft's Industrial Design Engineering faculty, where some materials that were necessary for the test were available. Participants arrived in the room of the lab, where they sat down at the same table. The actuators were attached to the inner side of the non-dominant wrist of both participants in a similar fashion to the previous experiment so both could feel the vibrations, with cohesive bandages.

The participants were then given some instructions on the nature of the experiment, the similarity to charades, calling the game "haptic charades", how the sender had to remain silent while creating the vibrations, and given up to 3 minutes to try its functionality, before the experiment started. The experiment was divided in 2 rounds of 2 sets with 3 emojis each, making a total of four sets and 12 emojis to be guessed. Between sets, participants switched roles, so each participant was a guesser and sender twice.

To make it a bit easier, the guesser was given a list of the emojis in that set. There is a limit on the insight that vibrations can give about the emotion and without this help, it would have been impossible to pinpoint with precision the transmitted emotion.

The first round was made with the participants facing each other, with the only limitation being that the sender could only use the vibrations to communicate. However, in the second round, participants were isolated using a curtain, so we limited the information apart from the vibrations that the guesser was receiving.

After these two rounds, participants were sent a form (see Appendix 3) where they rated the experience and gave qualitative feedback about the experiment.

3.3.4. Results

The independent variables in the experiment were the emojis given to the participants, and the outcome measures were the parameters that the participant set in the UI for each trigger. The responses to the form responded to were more focused on qualitative feedback.

These were the results of the different variables, frequency, incident frequency and amplitude for each of the triggers. The variability is quite significant, although some interesting things can be observed. Regarding the arousal levels, for instance, the amplitude and incident frequencies follow significant trends (Fig. 32).

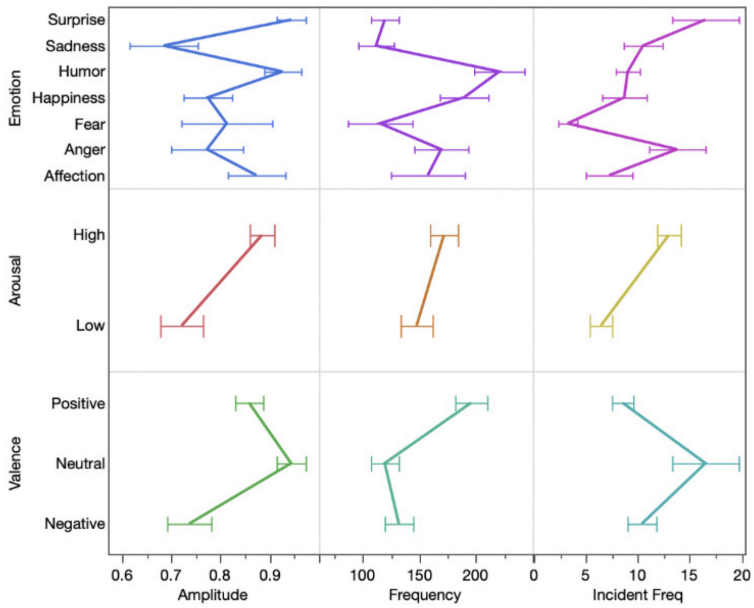


Fig. 32 - Parameters per trigger

Errors by Trigger

		High Arousal	***Low Arousal***
Set 1	Happiness	2	2
	Surprise	2	-
Set 2	Sadness I	-	0
	Anger	1	1
Set 3	Fear	-	2
	Humour	6	1
Set 4	Affection	3	-
	Sadness II	1	1

The experience was rated as highly positive (4.5/5), with engaging and fun (85.7%) being the words most associated with the experiment in a multiple choice question. Participants were asked if they got to feel the emotions that the emojis were representing, and the result showed that they agreed with the statement, the average response being 3.78 out of 5.

Participants liked both guessing (4.57/5) and sending the vibrations (4.18/5), and both guessing (2.92/5, 5 being maximum difficulty) and dialing (2.78/5) the vibrations were found moderately difficult. The variable that helped participants the most was the frequency, followed by both incident frequency and volume (Fig. 33).

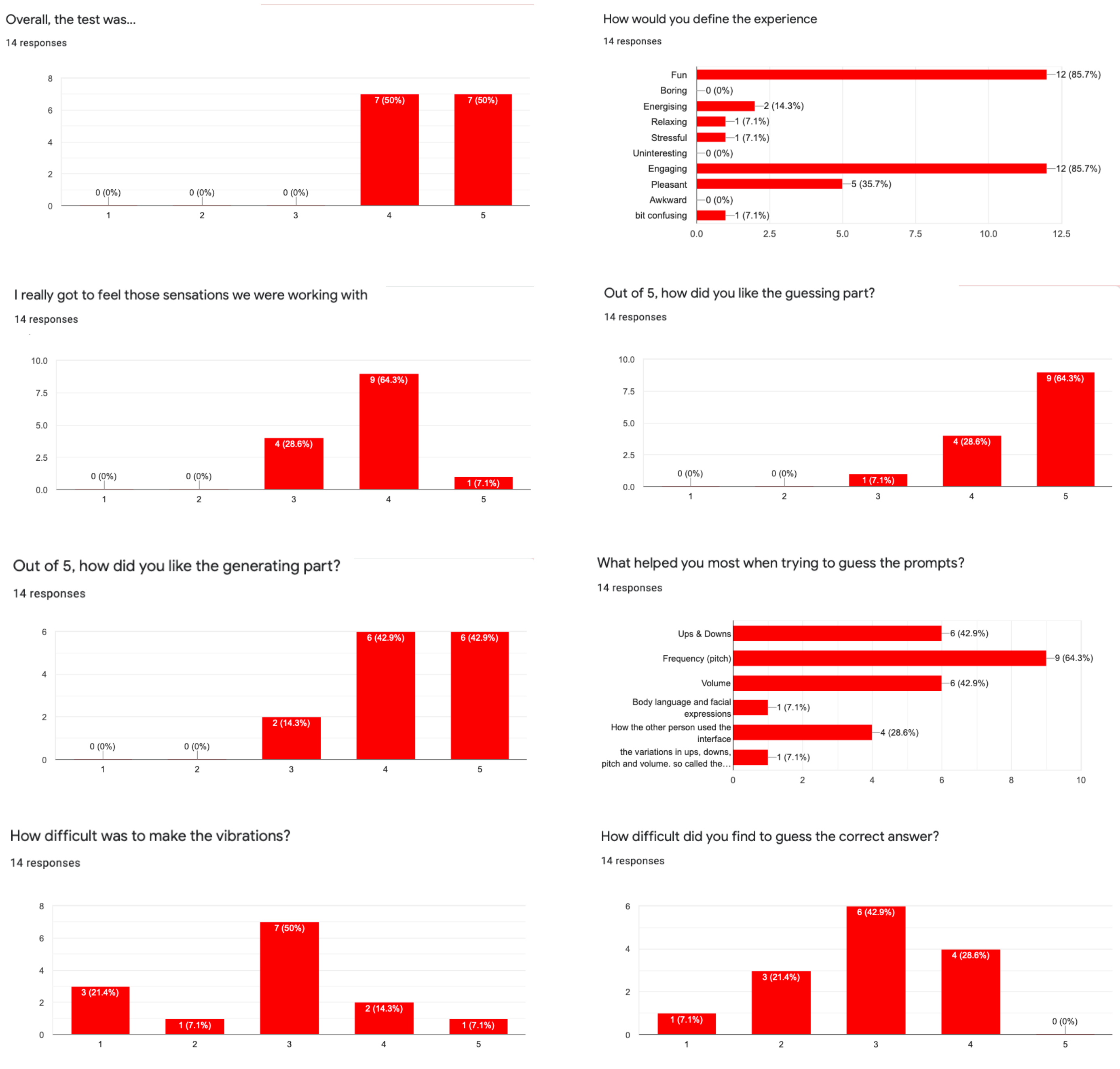


Fig. 33 - Responses to the post-test form of experiment 2

3.3.5. Conclusions

Interactivity of tactile vibration signals

Even though this test was about communication and interaction through haptics, it shone light on a very important topic: interactivity. While in the first test participants were allowed to freely interact to discuss the haptic stimuli they were co-creating, the interactive and immediate character of the continuous vibration opened a new gate to how participants could communicate using VTS. Being able to generate and control the stimulus in real time was something that helped not only for people to be able to engage in a feedback loop like in the actual charades game, but to also perceive in real-time the exploration process (Fig. 34).

When asked about what was the thing that helped them most to guess the prompts correctly, even though the option was not given in the multiple choice, 5 people signaled that how the other person conducted the exploration of the vibration space before settling for an option they liked was what had helped them most.

The continuous vibration format, different from the envelopes of the previous experiment, seemed to allow people to understand the mechanics of the vibrations better, which translates in the guesser being aware of what the sender was looking for and getting as much insight from the exploration process than from the final vibration itself, at least in some cases.

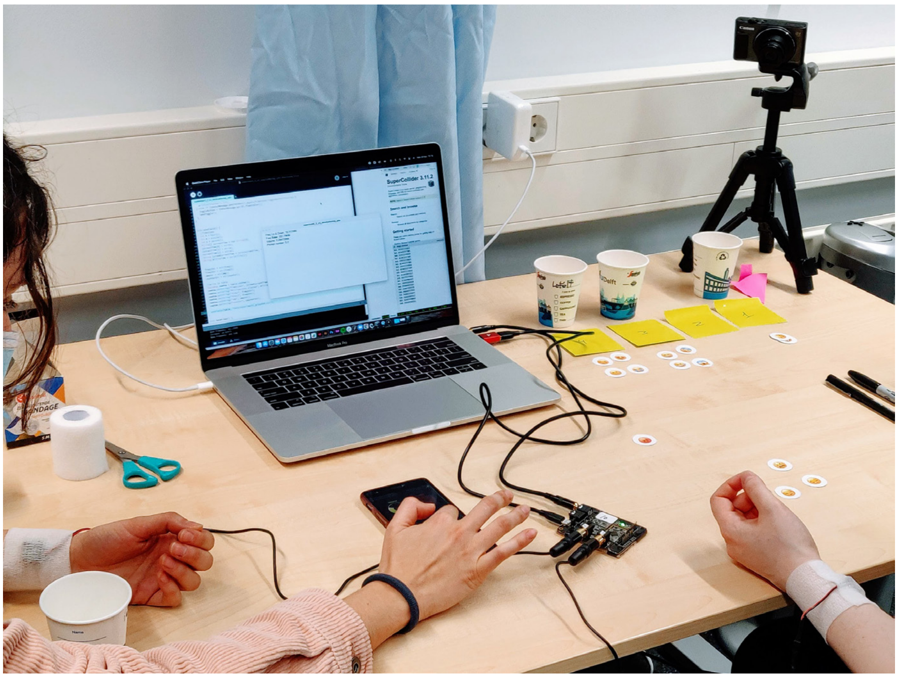


Fig. 34 - Participants using the interface during experiment 2

Feedback loops

It was also interesting to see how feedback loops were created. Even though people initially had different understanding of how different vibrations correlated to different emotions, when the pairs of participants established a dynamic of expressing out loud what their interpretation was of what they were feeling, they were able to create a common ground for understanding each other (Fig. 35).

This meant that although participants may have started with different ideas on how vibrations represent each emotion, they could adapt their perception to each other's and generate an understanding of what the other person expected of each emoji. At the end of the experiment, participants were asked if they got to feel the sensations that they were communicating, and all of them responded positively to this, so their perception and sense-making had adapted in the interaction.

Although there is some consistency on how people express some of the emojis through vibrations, there is not really a perception on how certain emotions should feel and how different cues and triggers are expressed. This leaves it to haptics designers to design and test channels through which people can interact dynamically in order to create their own meanings and understanding in what could be called *augmented participatory sense-making.*

When participants were asked about this feedback loops, these were some their responses:

> *"When the guess was wrong I could understand what kind of vibrations my partner linked to a certain emotion, and change my vibrations accordingly"*
>
> *"I got to know how the other participants tend to describe an emotion and then took that into account at the next round."*
>
> *"I would listen to their feedback to try to understand how they interpreted the vibration. If we were not on the same page then I changed the vibration to try to guide them to the correct answer"*

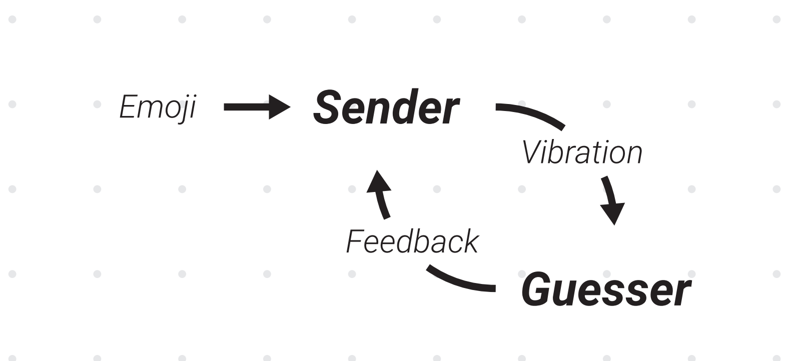


Fig. 35 - How feedback loops appeared during the experiment

Reciprocity in interaction

Reciprocity was also a big part of this experiment, with people engaging more dynamically in the back and forth of vibrations and feedback having an easier time establishing the common ground between them and effectively playing the game compared to couples who did not interact as much. People were encouraged to speak out loud, but only some of the groups did (Fig. 35).

From the researcher's perspective present during the experiments, the groups that more enthusiastically engaged in the exchange of sensations made the sessions more fun, interactive and exploratory. This was not affected by the fact that the participants knew each other beforehand. Moreover, some of the groups with complete strangers were the ones that interacted the most. Participants discussed the different features of the vibrations after a correct guess and how the exploration had worked, what surprised them from the final result, different features of the interaction and overall, made the session more interactive.

This obviously also helped to perform better in the game, with groups in which participants interacted less, the amount of missed guesses was higher, with an average of 4 misses in the groups who interacted less, while the average in the teams that interacted more was 2.5. This was from a total of 12 emojis, so couples that were not as engaged still got to build an understanding of what each of them expected from the vibrations.

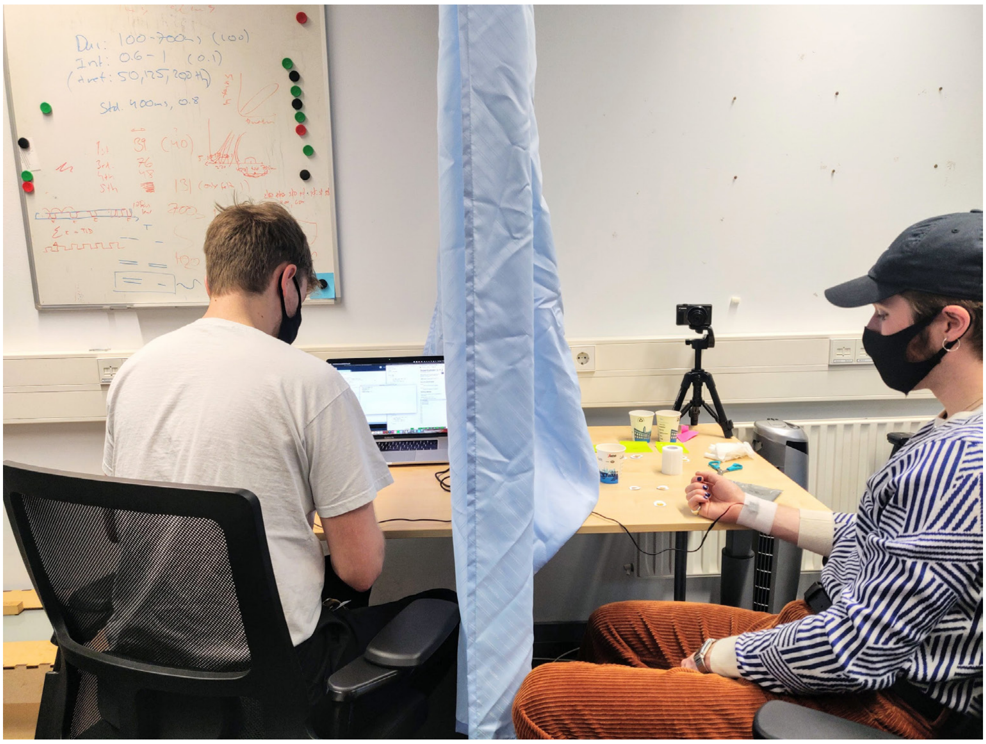


Fig. 36 - Participants were isolated in the second part of the experiment, but they had built an understanding together

3.4. Experiment 2.5 - Perception of Pulses

To know if there was consistency on how different participants perceived VTS, 5 of the envelopes created in experiment 1 (see section 3.2) were played to 10 of the participants in experiment 2, after finishing the experimental procedure for that session. As the setting of the actuators was identical to the one in experiment 1, nothing had to be changed in order to display the envelopes.

In this case, there was no interaction or usage of an interface, but the pulses representing the vibrations were played three times in a row, so participants could feel them fully. Then they were taken to a Miro board where they could locate the stimulus in the EmojiGrid (Toet et al. 2018) (Fig. 36).

10 participants took part in the study, of which 3 were female. All of them students at the TU Delft, of ages ranging from 24 to 27. They had all just completed the procedure of experiment 2, so vibrations were not new to them.

3.4.1. Results

Consistency on the perception of the created stimuli

The results show that in some of the pulses there is some consistency in how participants perceived the different stimuli (Fig. 37). This means that although certain patterns appear, there is still a lot of individual variability in the perception of haptic vibrations. Understanding valence proved to be more difficult than arousal, where there was more consistency in the responses. The hypothesised location is the red dot, taken from Russel's circumplex model of emotion (Russell, 1980).

The most curious cases are related to *affection* and *yellow*. Which are the ones where there was most consistency. It is usually not easy to get low arousal and polarised valence, but those two stimuli created consistent responses in the positive and negative valence in the regions of low arousal (Macdonald et al. 2020).

Table of Triggers

	Attack T	Sustain T	Release T	Amplitude	Frequency
Finger Snap	0	0.138	0	1	284.1
Anger	0.18	0.18	2.21	1	192.1
Yellow	1.6	0.2	1.6	0.61	215
Usain Bolt	1.12	1.9	0.5	0.5	234
Playful Push	0.38	0.5	0.5	0.36	158.1
Blue	0.25	2.3	0.37	0.68	192.46
Affection	1.58	0.8	1.61	0.4	89

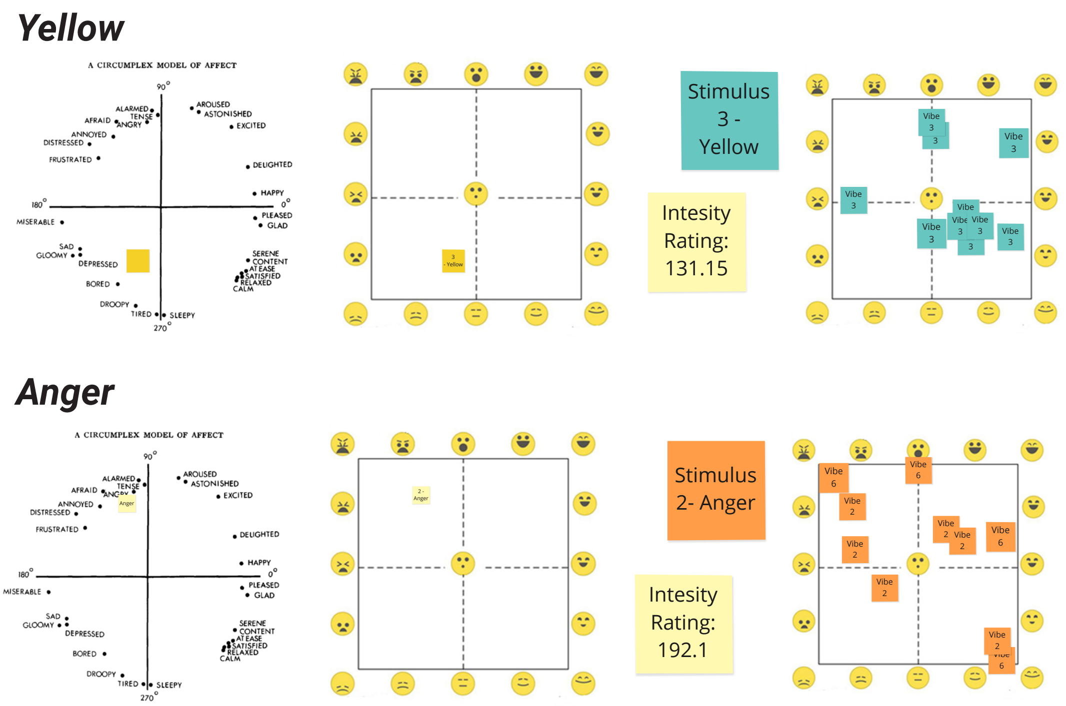


Fig. 37 - Miro was used with the participants to locate their perception in the EmojiGrid

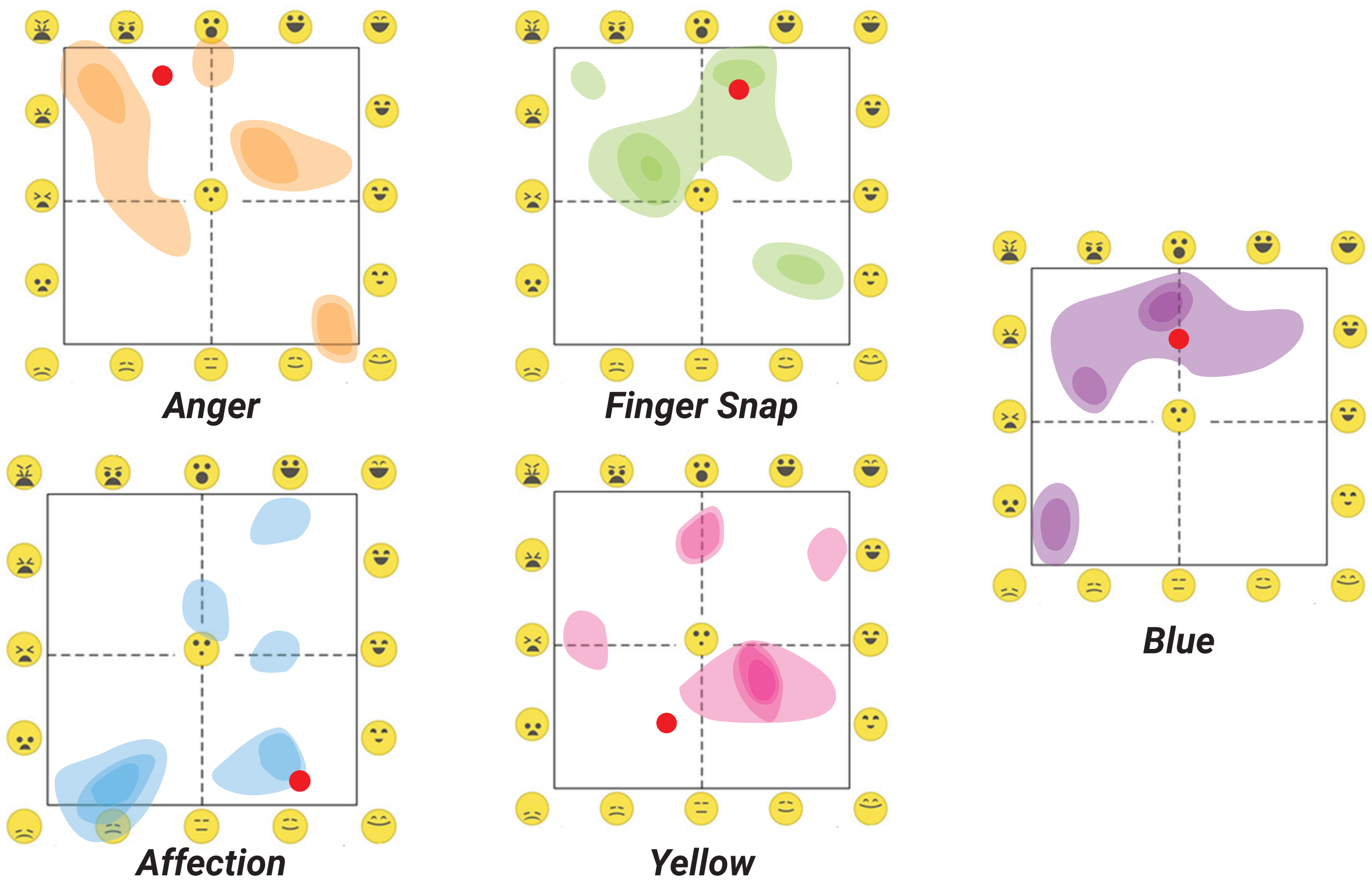


Fig. 38 - Perception of the envelopes created by the participants

3.5. Takeaways of the Experimentation Run

VTS are a suitable mean to create rich and engaging interaction

As confirmed by the first experiment, there is not a wrong answer to what can or cannot be sent through VTS. Participants got to feel the sensations they were sending in all the cases, no matter the trigger format or the content, at least when co-located and able to discuss. This means that there is a lot of free range on what is possible to transmit through VTS.

The designed interactions were rated as engaging and fun, where participants got to successfully interact with and through vibrations. The experience in the two experiments was highly rated, and no matter the roles in which the participants had to perform, interaction through VTS showed promise if done the right way. Knowing this, the next step was to apply these possibilities to an interaction that adjusted better to the principles of enactive interfaces and embodied interaction.

Emergent nature of the meaning of VTS

The biggest finding on this experiment run is that even though there is a big amount of individual variability in how different cues are transmitted and perceived, while interacting, participants were able to make sense of the different vibrations they shared.

In the first experiment, participants reached agreements on how the envelopes represented the different triggers, although the pulses were definitely different between groups. In the second experiment, the same was observed, where couples established feedback loops between sender and receiver to effectively guess what they were trying to communicate.

This means that the meaning of the vibrations is not as much inherent to the different frequencies but is emergent from the sense-making process of the two participants engaged in interaction. By sharing their perception out loud and modifying the vibration in real time, groups could establish a common understanding of what the different parameters of the vibrations meant to be.

After experimenting with both envelopes and continuous vibration, to support ongoing interaction, the second option is the best of the two. Exchanges between people are continuous backs and forths, therefore it is necessary for the stimuli to allow the interaction to be reactive and immediate (de Jaegher & di Paolo, 2007).

The interaction in the second experiment, in which the participants communicated through a continuous vibration that they could change in real time, was more engaging than the first one, in which they relied on envelopes. Participants feeling the stimuli during the second experiment also remarked on the importance of feeling the exploration process of the sender during the second experiment to better catch the meaning of the vibration.

The continuous signal also allowed the sender of the vibrations to react in real time to the input of the receiver, facilitating the process of sense-making. This proved to make the sessions in which people interacted more engaging, and their results better.

To draw a simile with face-to-face interaction, when people communicate with each other, it is a continuous flow of information that is perceived, even when someone is not the one talking, and that information is continuously modulated and reacted to. The signal being transmitted was similar. From the experiments, the nature of the continuous signal and its change through time played a big role in the perception of the vibrations, the emergence of meaning in the interactions and the process of participatory sense-making (de Jaegher & di Paolo, 2007)

3.5.1. Next Steps

The two experimentation cycles had been interesting and fun to conduct, and had brought insight around the perception of meaning of vibrations in social situations. Continuing with the experimentation was an appealing perspective, but the goal of the project was not only to gather knowledge and present it, but to design an interaction.

Knowing that the meaning of vibrations is emergent from social interaction opened a big space of possibilities to play with, from the nature of the interactions, to the contexts on which to apply the VTS, to the people interacting and their relationship. Satisfied with the acquired knowledge, the next step had to take towards a final proposal for an interaction. This meant that it was time to conceptualise possible interventions to implement the knowledge gathered during the experimentation cycles.

4. Vibrification

With the experiments completed, the next step was to integrate all this knowledge in a design intervention for people to interact with each other. The goal was to create a, dynamic, embodied interaction through VTS. An interaction which would not focus on the exchange of explicit information, but that could capture the multi-sensory richness of human experience (Fig. 39).

The following phrase by Gaver and Strong defines the main problems present in modern UIs in a nutshell:

> *"Most current collaborative systems demand explicit communication. They rely on symbolic messages—usually language—which means that communicative acts must be overtly articulated by the sender, and that their reception is a relatively focused and attention-demanding endeavor for the recipient. The use of symbols also implies that the process is one of transferring information, whether about facts or opinions or beliefs. Finally, the broad purpose of current systems is to support goal-oriented behavior such as planning, design, or problem-solving, in which communication serves some external aim" (Gaver & Strong, 1996, p. 30).*

Although they wrote it 25 years ago, it still holds true. The ways people interact with each other through our digital technology mostly rely on symbolic communication and demand a high level of attention, and are focused on the transmission of articulated information. The intention was to flip this premise upside down and allow people to interact through transparent interfaces (see the Enactive Torch example in section 2.1.4) that allowed them to engage in action and use that as input for an interaction.

Fig. 39 - There is more to human experience than information exchanges

4.1. Capturing the Periphery of Interaction

One of the examples that was used the most when trying to explain the physical interaction part of the project, was couple dancing. Dancing is one of those interactions that cannot really be done using the current interfaces in our devices, or if it could be, it would hardly be the same as the real thing (Fig. 40).

That is because, as Gaver and Strong say, the main purpose of the systems that are used to mediate interpersonal communication are not meant to transmit the kind of information necessary for dancing together. This information is not articulated knowledge or information that can be transferred through symbolic means, therefore it is not well suited for the current means available to communicate with each other in a mediated way.

Similar to couple dancing, there are a lot of interactions that cannot be replicated with the channels available to designers nowadays. Moreover, the information that lives in the periphery, meaning that it is not the main focus of communication, and that makes face-to-face encounters rich and engaging, is lost in the channels we use to communicate with each other (Gill, 2007).

A lot of the emotional and affective information is contained in this space that cannot be communicated, as it is a multi-modal and multi-sensory. One example is what Satinder Gill (2007) describes in her explanation of *Body Moves*, which are “bodily actions which initiate or respond to bodily actions or verbal utterance (...) representing a response or initiation, sometimes in the same moment as the bodies and speech move together” (Gill, 2007 pp. 28).

This is only one theory within this wide space of research, but the takeaway was that these parts that are treated as peripheral and secondary, are crucial for the regulation of social interaction.

Fig. 40 - Couple dancing is something impossible to do with the current digital technology

That was one of the main questions that was faced during the development of the final interaction concept of the project, how to capture and display the kind of information that could allow people to elicit feelings similar to the ones produced by couple dancing. Could this system capture the rich and multi-sensory side of human experience and encapsulate it in an interaction which elicited emotional responses?

4.1.1. From Sonification to Vibrification

The response to this question was Vibrification.

The term is inspired by sonification, which in the field of acoustic displays, has been studied for decades. It started as an alternative that uses the human capacity to discern pattern shifts and changes in acoustic signals to display multidimensional data though non-speech audio (Kramer et al., 1999). Music is a great example of this capacity, in which the shifts in certain rhythmic patterns can change how we perceive it, even subconsciously. A great example of this is the analysis that Altozano made of the Lord of the Rings soundtrack, in Spanish (Altozano, 2017)

After 25 years of research, true auditory displays that represent data by modifying an audio signal are maturing, and sonification has grown in complexity and scope. However, it is still quite experimental and not yet widespread in the consumer market. Still, interest in these techniques is growing quickly, and sonification models are being put to the test under scientific conditions more and more (Hermann et al., 2011).

A great example of sonification is the sound of electric cars. Internal combustion engine (ICE) cars naturally produce sound when they are operating because of how the ICE works, so when drivers accelerate, the engine revving up creates a characteristic roaring sound. Electric cars, on the other hand, have electric motors, which are almost silent. This meant that drivers had lost the reference of the engine revving up when driving, which many of them used to know at what rate they are accelerating, and the satisfactory sound of the engine delivering power.

Some car manufacturers added to their electric cars sounds that play through the speakers in order to give drivers the sensation of revving the engines up, and the auditory cue of accelerating for safer driving. BMW for instance, hired the famous film music composer Hans Zimmer to create the sound of their electric concept car Vision M NEXT (Peters, 2021).

The example of the electric car is a good one, because it speaks of the layers that are lost when changes are made to a system, sometimes unexpectedly. Car manufacturers tried to recapture that experience of pressing on the throttle of a gasoline car and putting it on an electric one, and in the case of BMW, they went one step further and re-imagined how that action should sound (Fig. 41).

The concept of Vibrification is at its most basic definition translating data into mechanical vibrations that can be sensed through the skin. The idea of haptic displays already exists in the research space, but there has not been a definition of a field that specialises in the conversion of data into tactile vibrations for haptic displays, specially to create emotion eliciting vibrations.

Fig. 41 - Hans Zimmer poses with the BMW Vision M NEXT (BMW Group)

4.1.2. Why Vibrification?

The application in this project uses that basic definition of transforming data into tactile vibrations, but takes it a step further (Fig. 42). The application of that concept is using biosensor data as the means of capturing the information that our current digital devices cannot, the information that is usually in the periphery of interaction, but sometimes is in the middle of it like when hugging or couple dancing, and deliver it in a way suitable to create an emotionally rich experience.

Back to the hugging example given in the introduction (section 1), the aim was to capture and display the kind of information that could allow a digital mediated hug. The crucial part found in the experiments was that the signal had to react to the actions of the participant in order for them to make sense of it and create an attribution loop.

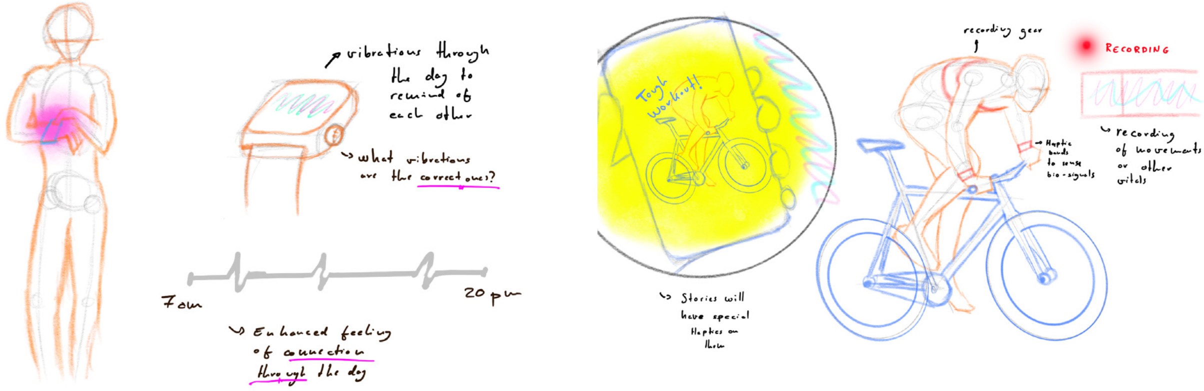


Fig. 42 - Two concepts that used Vibrified biofeedback to capture experience

This was how the idea of Vibrification emerged. The power of the attribution of vibrations to real world sensations has been suggested by Macdonald et al. (2020), but they also found that the effect was only significant when participants made the connection between the vibration and the real world, which not always happened. The meaning was not found in the vibration, but in the connection to the source, when the participant made sense of the vibration.

To create an interaction between two people, the idea of Vibrifying biofeedback came quickly, as it aligned with the idea of capturing peripheral information. Biosignals can be a good reflection of the internal state of a person, as Abraham John et al. found in his masters thesis *Project Vital* (2021), and they reflect what is happenning to them, so it could make sense that they are suitable to act as a substitutes to the kind of information that is sometimes lost in mediated interaction .

For the kind of interaction that was envisioned from the beginning, hugs and couple dancing, biosignals are also intimate signals that often can only be sensed when in close contact with another person. Biosignals were potentially a good option to design an interaction that could elicit emotion and trigger empathetic responses, so the next step was to test if this was the case.

4.1.3. Vibrifying Breath

When it was decided that Vibrification was the way to go, the next step was to conceptualise and explore the space. Sketching and discussing with the supervisory team the most interesting directions was the way this was done, and also a speed dating run was held. Some of the most interesting concepts are presented in appendix 4.

While engaged in this process of sketching and discussing what signals could afford the most interesting interactions, breath appeared to be the most promising of the signals to Vibrify as a first exploration of the concept.

Breathing, although a reflex, is still a biosignal that can be consciously controlled. This was crucial in a first exploration of the space, as it allowed the creation of the loop between signal and action and, therefore, it is easy to understand the signal from a user's standpoint. Other signals, like heart rate, were discarded because although they can have powerful effects, do not allow this to happen.

Fig. 43 - Thoracic activity sensors had to be designed and manufactured to capture breath

Breathwork is used in a myriad of different practices as a way of controlling the internal state of people. To give some examples, yoga, vipassana meditation, and breathing therapists use breath to control thoughts, encompass movements and concentrate. Some practitioners have had success physically controlling their bodies to incredible extents partly by using breathing techniques, like Wim Hof (Kox et al., 2014).

The study by Macdonald et al. (2020) also gave a good justification on why breath was a good option for the project. Some vibration stimuli that related to personal experiences elicited stronger emotional responses in their study than abstract tactons or stimuli that participants did not recognise. In this case, the idea was taken one step further, as the signal could be directly attributed to a social agent actively interacting in real-time.

The pattern of breath is also promising compared to other biosignals for its aesthetic characteristics. In Sweet Sensations (section 2.2.4), patterns with slow (0.3 to 1 Hz) incidents were found most pleasant and interesting. These long incident frequencies give the waveform a “breathing” effect of slow ups and downs in amplitude, so it was hypothesised that the sensation of feeling breath would make for a pleasant experience.

It was also a simple biosignal to Vibrify. Designing and creating a waveform that followed breathing seemed like the biggest impact per time spent. Sensors for measuring breathing that can be integrated within the existing toolbox were not easy to come by, but designing and making a breathing sensor proved to be easier than expected (Fig. 43).

To get familiar as quickly as possible with the nature of the signal and the best way to create an interaction through breath, an exploration workshop was held at the TU Delft’s faculty of Industrial Design Engineering, to bring designerly insight to the project in order to create the best interaction possible.

4.2. Hands on Vibes - Co-creation workshop

The idea of the Hands on Vibes workshop was to bring people together to experience the technology that was available for Vibrification of breath, let them prototype, experience and generate experiential knowledge that they then could present as the outcome of their sprint session.

Session goals

- Allow participants to experience the vibrations and the technology as a concept test for Vibrification of breath
- Get technologies tested and validated by the participant's exploration process
- Get insight from the participants' exploration of Vibrification

The session was meant as a hands-on sprint workshop where participants could prototype and experience the technology that was being used for the development of the Vibrified breath (Fig. 44). Instead of conducting the final experimentation run with a model based on assumptions and self-testing, the possibility arose of bringing people from the TU Delft to collaborate in the creation of insight that would help to create a final model of Vibrification of breath.

This served to develop, test and iterate different aspects of the Vibrification of breath simultaneously in an experiential manner, something quite unique in the design and development of haptics. Collaborative sessions for the development of haptics are challenging to plan, as the technology is highly specialised and the software and hardware required to control them are unfamiliar to most people.

To allow free exploration with VTS, an assortment of vibration actuators were available for the participants, from small voice coil actuators to tactile speakers. To control the actuators, two breath sensors were available and two computers with different software to customise and create the vibrations.

The expected outcomes were concepts for a joint breathing session, with an explanation of the insight that backed them up and how the prototyping and experiencing had gone. Although the final outcomes were not concepts, but only the insights that had been found, they proved to be crucial in the development of the final experimental setup of the project.

Fig. 44 - Participants of the workshop feeling vibrations from an Aura Transducer

In total, 11 students from the TU Delft participated, without counting me or the supervisory team that were also present during the session. Four of the participants were female. 5 of the participants were familiar with haptics in the past, although they had little experience on the technical aspects of the session.

4.2.1. Hardware Setup

The equipment available to participants was:

- Laptops running controller software
- LoFelt L5 actuators
- AuraSound AST-2B-4 Pro Bass Shaker
- DaytonAudio Puck Tactile Transducers
- Custom made thoracic activity sensors

Laptops and control software

Participants were given software running on two laptops running MacOS to be able to create their own patterns and vibrations with an architecture similar to the one in the previous experiments, using Processing and SuperCollider. Of course, the majority of participants were unfamiliar with these tools, so I was present to aid them in modifying the software to what their concepts needed.

It was also helpful to show the participants the logic behind the software tools and how to modify some of the parameters of the vibrations, as this allowed them to be more self-sufficient and iterate on their own, without the constant need of technical support.

Tactile actuators

To allow participants to be as creative as possible in their exploration, different actuators of different sizes and power levels were available for them. The LoFelt actuators have already been described.

The other two options were bigger tactile transducers to create more powerful vibrations. The puck transducer could serve to create vibrations in wider areas of the body like the back and chest, while the AuraSound shaker could not only do that, but also make entire surfaces, like a table, vibrate in order to create shared experiences (Fig. 45).

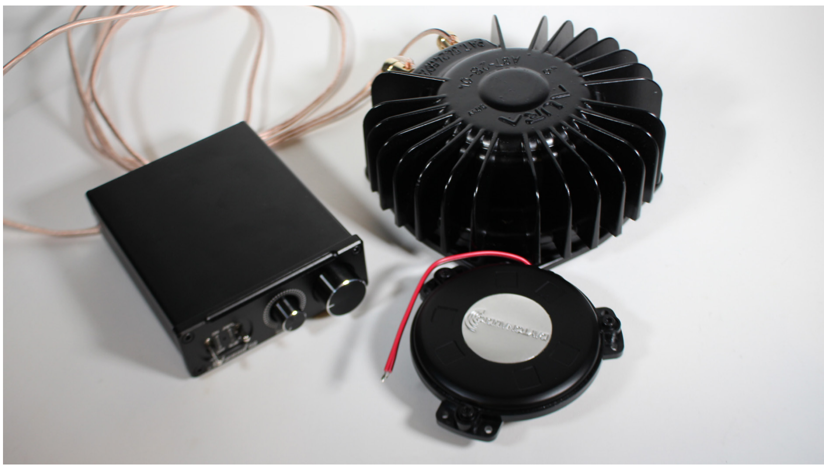


Fig. 45 - The Aura and Puck transducers

Torathic activity sensor

In order to capture the breathing pattern of one of the participants, two torathic activity sensors were built. They measured the expansion and contraction of the thoracic cavity and translated it into an analog signal read by a Seeeduino Lotus board. The values were outputted into the serial port and read by Processing in order to use them to create vibrations (Fig. 46).

Fig. 46 - A participant wearing the breathing sensor during the workshop

4.2.2. The Workshop

The session was presented more as a workshop than a proper co-design session. Participants were told to pop in and out whenever suited them best in order to see what was going on, experience what the rest of the participants had done and give their input and help create the next iteration. The session started with 6 people, and the rest of the participants joined in later stages. The whole session took 4 hours.

The workshop started with a 20 minute presentation of the project, with details on the goal and the idea of sharing breath through vibrations in order to allow people to interact with each other. Then the goals of the session, the idea behind the workshop and the expected outcomes were presented to the participants, and they were told that later some more people would appear to collaborate with them. The presentation ended with a quick showcase of the sensors, actuators and software.

The 6 initial participants were divided in two groups that could independently start conceptualising and prototyping. They were able to pick actuators, software and sensors and start developing by themselves.

4.2.3. Group 1 - Testing Waveforms

The first group took to themselves to test different kinds of actuators, positions and VTS frequencies to support breathing. They grabbed one of the computers and started tinkering with the synthesiser software and with some support, they created a synthesiser in SuperCollider that used a sine oscillator to create a cycling signal that could mimic breath.

From there they started to play with the different parameters of the vibrations and the oscillator to test how they felt, testing different parts of the body (Fig. 47) and even making the surface of a table vibrate. The goal was to find out how different positions, frequencies and experiences felt, from sitting on a table that vibrated, to a shared Vibrified breath experience, to touching each other to feel the vibrations in each other.

Fig. 47 - One of the participants with a Puck transducer on his chest

Results

The results of this group were related to the waveform and the devices to use in order to achieve different effects. They mainly used the AuraSound speaker, which was the most powerful of the three, but also experimented with the rest of the actuators.

For a group breathing session, they found that making a table vibrate and leaning with the forearms on it was enough to get people around it to experience the vibrations and entrain with the breathing pattern. In this case, they suggested using an approximated breathing rhythm, as thoracic data included depth of breath, which is not shared by all the participants. The suggested breath rhythm was 6 breaths per minute.

> *"We could feel the vibration in our shoulders and inside our chest and in our bodies (by leaning in the table with our forearms)"*

They also experimented with different positions on the body and the chest, over the heart was most comfortable. The experience compared to the group sensing one became solitary and the device more wearable-like.

> *"The vibration in my spine was affecting my diaphragm in quite a painful way, and making it clench a bit, while the other participant found that it created a numbing sensation after which he couldn't feel anything"*

For the frequency, they aimed to find a frequency that was suitable for a relaxing and pleasurable experience, and they settled for 50Hz which felt like a gentle guide for breathing. Frequencies lower than that the vibration started to get buzzy and could feel the peaks of the sine wave, which demanded too much attention and were uncomfortable.

4.2.4. Group 2 - Synchronisation in Breathing

The second group started by setting up the thoracic activity sensor and testing the experience of feeling another person through their Vibrified breath. They focused on the action of breathing itself and the possibilities to make the vibrations feel more like an understandable breathing pattern. They also tried to synchronise the breathing of two of the components of the group and see what could be improved in the vibration signal to make this process of synchronisation easier (Fig. 48).

They also explored the mapping of the Vibrification parameters, exploring how different people understood the polarity of the breathing (is an increase in amplitude exhaling or inhaling?), how is it to feel another person's breathing and how to improve synchronisation of two participants in the interaction.

Fig. 48 - Participants set up the breathing sensor and the LoFelt actuators

Results

Regarding the polarity of the mapping of the parameters, they found that people had different takes on the matter, but when they started sensing the vibrations, most people understood the increase in amplitude as inhaling, another example of the emergent character of the meaning of VTS.

The synchronisation of two participants in a breathing session proved to be limited by the sensitivity of the body. When the maximum point of amplitude was reached and started to decrease, meaning that the person with the sensor was at the peak of their inhale and started exhaling, the person sensing the vibration did not sense the change and lagged in their exhale (Fig. 49). This was not the case when the shift was from exhale to inhale, meaning that it is easier to sense a shift from low to high amplitude than one from high to low.

> *"Inhaling was easy to follow, because it almost stopped, it was easier to sense"*

Making the interaction reciprocal, with participants feeling each other could then translate into the two participants trying to catch up in an unpleasant experience.

To solve this, they suggested two options. First, mapping not only the amplitude but also the frequency to the thoracic activity in order to provide more information to the person sensing the vibrations. Second, shifting the position of the vibrations using an array, between positions that are sensitive to vibrations.

> *"It is really important that the person receiving the vibrations knows the peak of the inhale and exhale. It is not a pleasant experience to keep following the vibrations. And we never learned."*

Fig. 49 - The participants try to synchronise their breath through vibrations

4.2.5. Discussion

This workshop and the positive engagement of the participants on it proved to be invaluable in the design of the final interaction. Although the core of the idea was already presented in the workshop, “haptics for breathing”, it did not stop the participants in their exploration of the space, and the insight gathered in this session changed dramatically the initial idea for the final interaction.

Prior to the workshop, a device based on the one from the previous two experiments was going to be used. Instead of using one vibrator on the wrist, using two of them to create a simulated “inflation” effect in order to represent the breath of the participants. The idea behind this concept was the use of haptic illusions, but the design was the product of hypothesising (Fig. 50).

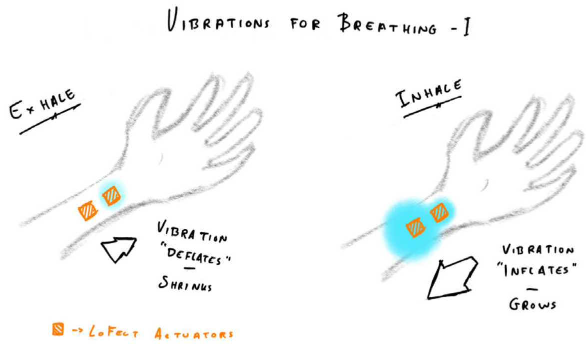


Fig. 50 - Proposed pattern before the session

Having designers participate in a co-creation session and letting them explore the space of haptic vibrations for breathing freely made it so the final prototype was based on actual experimental insight, and the focus of the test would not be the interface, but the experience itself. The session provided information on the best waveform, the actuators and the position best suited to the task and the kind of information expected from the vibrations to sustain the interaction.

Involving participants in the process of haptic sketching proved to be challenging for the technical complexity of the task. Participants in this case were mostly unfamiliar with the modality of the stimuli and the technology behind it. The key in this case was to provide a minimal explanation of the technical side of the task that they were pursuing so it would allow them to freely explore the space using the tools at hand.

As a way of quickly gathering insight on the topic of the perception of stimuli and the exploration of the space, allowing designers to quickly design, deploy, iterate and involve others seems to be a key step for the development of Haptic Interaction Design. The creation of tools that make this happen in a way that it adjusts to the design process will most certainly be welcome in the field of Haptic Interaction Design and Digital Interaction Design as a whole.

4.3. Experiment 3 - Sharing Breath

Experiment Goal

Get insight on how the proposed system supports the interaction of joint breathing

Know if the Vibrified breath triggers an emotional and empathetic response in people

Research Questions

Can Vibrified biosignals help support empathetic insight?

Is the proposed waveform a good representation of breath?

Is Vibrification a viable option to support embodied interaction?

Fig. 51 - The participant on the right (receiver) feeling the breath of the on on the left (sender)

The final stage of the project was to apply the concept of Vibrification and the learnings from the previous workshop (section 4.1) to an interaction and see if there was indeed an emotional and empathetic response. The selected interaction was a joint breathing session, similar to what a meditation or relaxing breathwork session would be, but doing it with another participant through VTS (Fig. 51).

The final experiment of the project was to create an emotional interaction between participants through Vibrified breath. To do so, a thoracic activity sensor was connected to a computer running a Vibrification algorithm that outputted a waveform to a tactile speaker. The procedure of the test was divided into two different parts: The first part consisted in participants feeling their own breathing through tactile vibrations; and on the second part, one of the participants got to feel the other's breath.

The sample size consisted of 4 couples (N=8, of which 5 were female) of students from TU Delft, 4 of the participants were in the range of 18 to 25 and the other 4 were in the range of 26 to 30. 5 of the participants had previous experience with breathwork and breath related exercises. 1 of the couples considered themselves friends, 2 of the couples had seen each other some time and the last couple did not know each other at all. 4 of the participants had previous experience with haptics.

Participants were asked to respond to a questionnaire (see Appendix 1) between the different parts of the test both about the aesthetics and the experiential part of the interaction.

4.3.1. System Overview

The proposed system is comprised by four elements (Fig. 52):

- Two custom made thoracic activity sensors
- Two DaytonAudio Puck Tactile Transducer TT25-16
- A master laptop able to send signals
- A receiver laptop to receive signals

Fig. 52 - Test setup from the side of on of the participants

Torathic activity sensors

The purpose of the torathic sensor was to capture the data of the participant's breath to be Vibrified. The device relied on a piece of conductive rubber held by a pair of alligator clips that connected two straps of safety belt-like material, and was adjusted using velcro. The contraction and extension of the thoracic cavity stretched the rubber, changing the resistivity of the piece of rubber, which provided an analog signal to the software.

The conductive rubber was Images Scientific 2" Flexible Stretch Sensor. When relaxed, it has a nominal resistance of 1000 ohms per linear inch. As the stretch sensor is stretched the resistance gradually increases. When the sensor is stretched to 150% of its original length (2" X 150% = 3"), its resistance will approximately double to 2.0 K Ohms per inch (Images Scientific Instruments Inc., 2005).

The sensor was connected to the analog Groove header of a Seeeduino Lotus v1.0 board running a smoothing software averaging the 50 last readings, allowing a stable output of the analog signal with minimum latency and avoiding spikes. Each sensor had to be recalibrated after each exercise during the session, for its sensitivity greatly affected the waveform of the vibration pattern, and any small movement by the wearer would affect its performance.

Tactile actuators

The element that transmitted the vibrations to the participant was a 16 Ohm DaytonAudio PuckTM TT25 bass shaker (Fig. 52). This transducer is relatively small (90mm diameter), making it a suitable solution to be attached to the participant's body, but it creates a more intense sensation compared to the Lofelt L5 voice coil actuators used in previous experiments. The tactile actuator was strapped to the participant's body using cohesive bandages used in previous experiments and reinforced with paper tape when needed.

The location of the actuator was the chest, as in the previous ideation workshop it had been discussed that although more bony areas are better suited for precision, something that research has shown in the past (Gemperle et al., 2003), areas with some body mass to dampen the mechanical vibrations made for a more pleasant experience. Therefore, the left or right parts of the chest were the selected location for the actuator.

The transducer has a 4 layer voice coil with a 1 inch aluminium former and 16 ohm impedance, with a usable range of 20 to 80 Hz, a range that was suitable for the waveform to be used in the experiment.

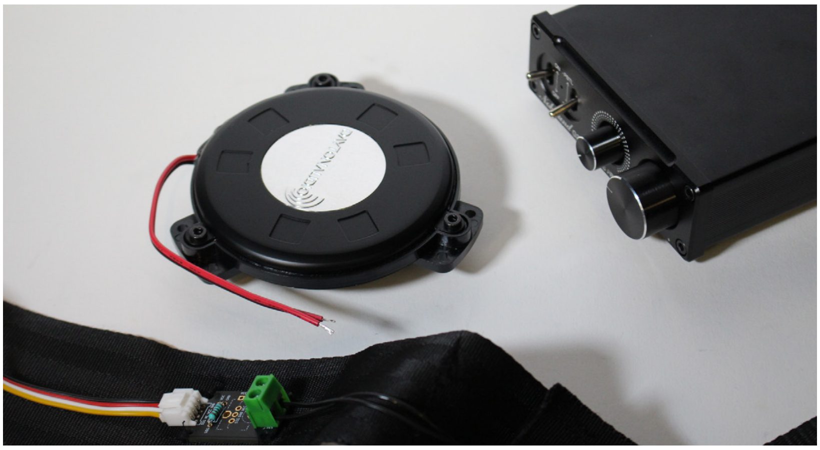


Fig. 53 - DaytonAudio Puck Tactile Transducer

Computers and software

The experimental evaluations of this project relied on the synchronisation of various pieces of software working together to record and process the input of the sensor and convert it to waveforms that the transducers transformed into tactile vibrations in real time. The overall architecture employed in this work is organised as follows.

The thoracic sensors, as previously mentioned, were connected to a Seeeduino Lotus board's analog ports. The Arduino IDE software running in the computer smoothed the signal of the sensors and then outputted it to the serial port at a baud rate of 9600 characters per second.

The serial port outputted the signal to a Processing program running in one of the two computers running MacOS, setup to run the signal from the sensor through a Parameter Mapping algorithm that modulated the frequency and the amplitude parameters of the waveform. The calibration of the sensors was done at this stage, at the same time as the mapping of the signal to the different parameters.

Finally, the mapped signal was sent via OSC protocol messages to SuperCollider to create the final waveform. The values for the amplitude and frequency of the vibrations were added to OSC messages that the local host server running a synthesiser in SuperCollider could transform into the output sine wave.

The OSC protocol in processing also allowed communication between both computers, as they were both connected to the same WiFi network. To do so, both machines were set up as master and receiver, where the master sent the signal of the sensor to the receiver that could output the reading of the sensor from one participant to the other, which would be necessary for a part of the experiment.

4.3.2. Feeling Vibrified Breath

There was no research on the effects or mechanics of controlled breathing prior to the experiment, as the goal of the experiment was not focused on guiding or supporting breath related practices, but about how feeling Vibrified breath helps people to be aware of their internal, the other participant's emotional state and the emotional reaction this may cause.

Waveform

One of the principles of enactive interfaces is that the interface has to become transparent, for the user to experience the world through it rather than the interface itself. In the case of Vibrified breath for a breathing session, the goal of the vibration was to accompany the breath in order to increase the awareness of the participant of their own breathing.

This required making a wave that on one hand felt natural and non-disruptive, while on the other hand had to create a pleasant and relaxing experience that would help participants focus. One of the key aspects of transparent interfaces is the fact that users have to focus on experiencing the action instead of the interface, so the waveform was developed according to principles found during the workshop (Section 4.2) for them to concentrate in breathing and feeling the other, not the vibrations.

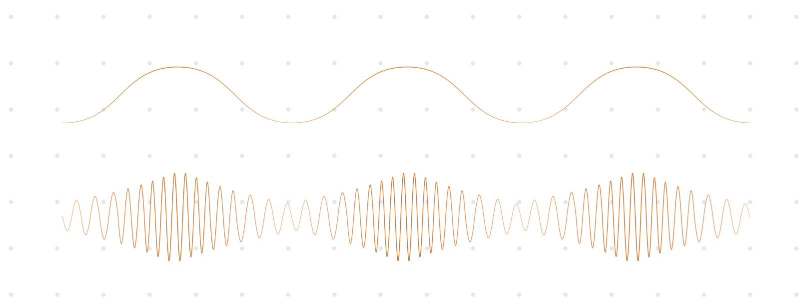


Fig. 54 - Representation of the breathing (top) and the waveform (bottom) - Not to scale

To create the waveform, the parameter mapping technique developed in sonification and tested in the workshop was used. This technique consists in taking some of the parameters of a waveform and mapping them to corresponding variables from the data to be sonified, or Vibrified in this case. As there was but a single data input coming from the breath sensors, it was mapped to two different variables of the wave, the amplitude or intensity and the frequency or pitch.

The waveform varied from 40Hz and 30% amplitude on the bottom of the exhale to 60Hz and 100% on the top of the inhale (Fig. 54). From the workshop, we had learned that a variation in amplitude is not enough to represent the breathing pattern, so a variation in frequency was also added. The frequency was chosen corresponding to what had been found to be the most pleasant frequency to represent breath, 50Hz.

4.3.3. Test Procedure - Incremental Experiments

To test the effectiveness of the system and study the effects of feeling themselves and the other in a joint breathing session, the procedure was designed in incremental steps, in order to let participants get used to the interface and the vibration input. This procedure was inspired by the social walking experiment conducted by Baldi et al. (2020).

The experimental process was divided in two parts: Feeling Yourself and Sending Breath. Each of the parts was divided in two, a short 3 minute warm up followed by a longer 7 minute session. This allowed the participants to understand how the vibrations corresponded and reacted to their breathing. During the long sessions, the first 60 seconds the vibrations would be off to create a baseline. The participants' thoracic activity was recorded using Processing.

After each of the four stages, participants responded to a survey (see Appendix 1) about the aesthetics and the qualities of the interaction, to keep track of their experience on the computer during each phase of the process. The form included ratings of the pleasantness, interestingness and intensity, descriptions and other qualitative questions. The final step of the procedure was a short interview recorded for showcase purposes.

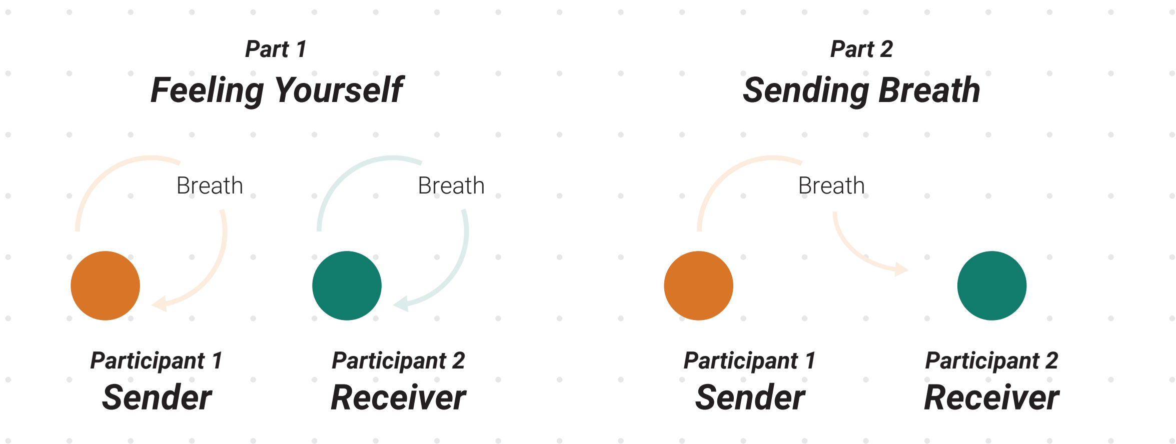


Fig. 55 - A visualisation of the structure of the test

The reason why the experiment started with participants feeling themselves was for them to get familiar with the waveform and the mapping of the breath to the vibrations. When the second part of the experiment arrived, the “receiver” of the breath could better relate to what the “sender” was doing, and the “sender” would know what the “receiver” was feeling (Fig. 55).

4.3.4. Results

Feeling yourself results

Although the effects of the VTS are varied between participants, in most of the participant’s patterns there is a clear difference between breathing with and without vibrations, while others remain unmoved by the vibration. The following graphs show that (Fig. 56 - 61).

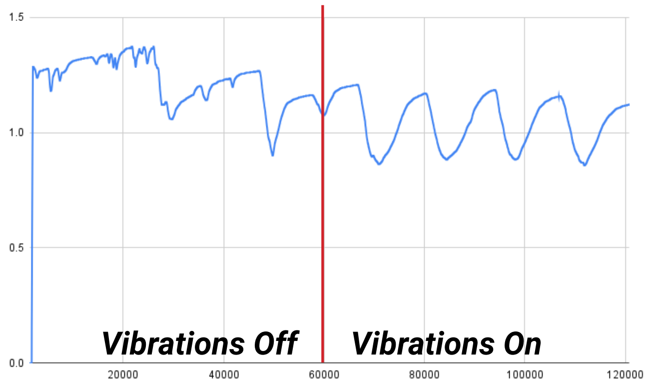


Fig. 56 - Participant 1 - more regular breath

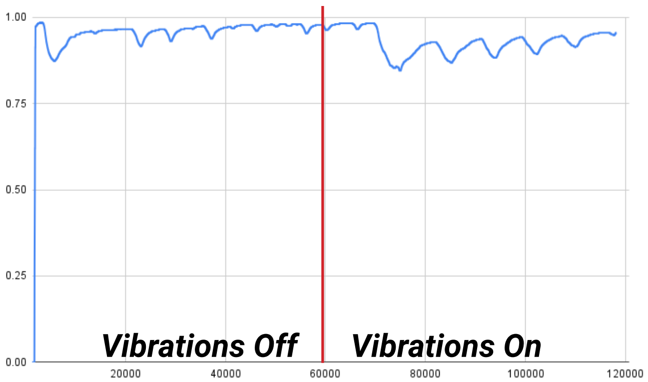


Fig. 57 - Participant 4 - more regular breathing

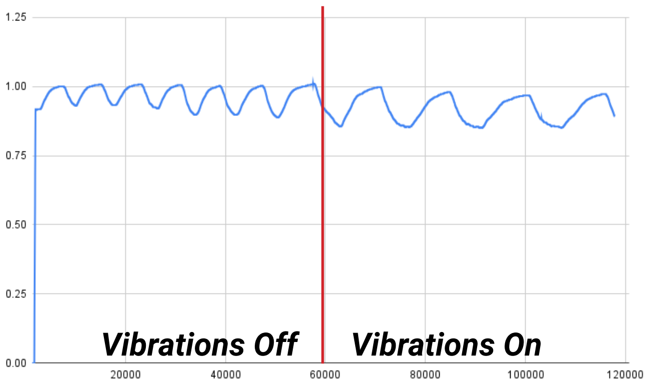


Fig. 58 - Participant 6 - longer breaths

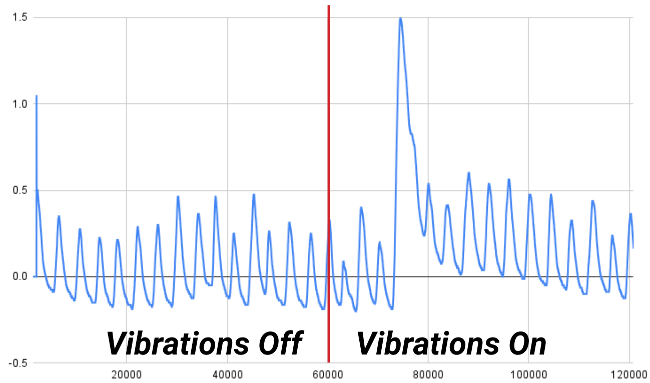


Fig. 59 - Participant 3 - a spike

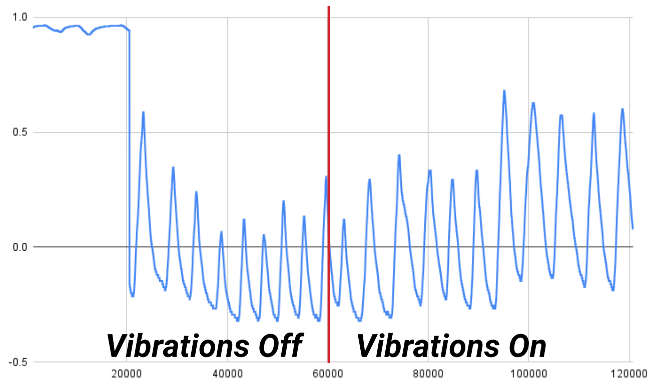


Fig. 60 - Participant 5 - Deeper breathing

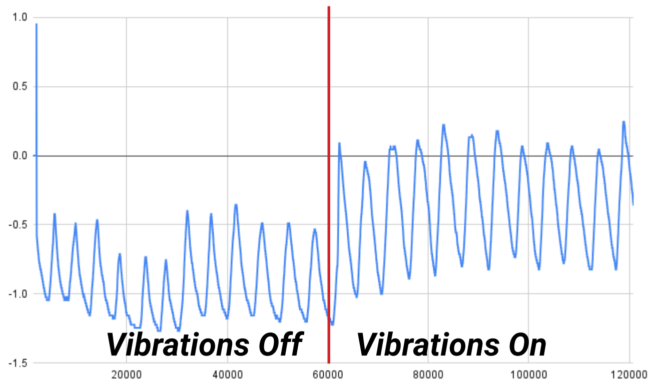


Fig. 61 - Participant 7 - Deeper breathing

On the other hand, the results of the final form show that the vibrations had positive effects across the board. The experience was highly rated by the participants (8.44/10), with participants describing the experience of feeling themselves in a prolonged session from a checklist of terms as pleasant (88.9% of participants), relaxing (88.9%) and immersive (77.8%). The assessment of the aesthetic experience of feeling their own breath was very pleasant (9/10), moderately intense (6.4/10) and very interesting (8.7/10). The low rating of the intensity is most probably related to how relaxing the experience was. This confirmed the hypothesis that breathing patterns with low frequencies are indeed pleasant to feel (Fig. 62).

*After the pilot test, this question was changed from out of 10 to out of 7

Fig. 62 - Responses to the post-test form of the final experiment - 1

The vibrations were very helpful to concentrate on the breathing (6.67/7) and they were moderately helpful to help increase the awareness of the internal state of the participant (5.44/7). Finally, the waveform was described as relaxing (88.9%), pleasant (77.8%), smooth (66.7%) and soothing(55.6%).

Some of the participants described the experience as follows:

> *"It really helped me to follow my breath, decrease the speed and relax in general"*
>
> *"By closing my eyes and having a longer period of time to experience the vibrations I was able to zone out of the real world much more and therefore relax much more."*

Sending breath results

The effects of feeling another person through breath were also varied, and the pool of information was narrower, as one person was sending their breath and the other was feeling it, therefore, only 5 participants got to respond in this case. The graphs show a varied response to the other person's stimulus, although in most cases it affected the receiver (Fig. 62 - 65).

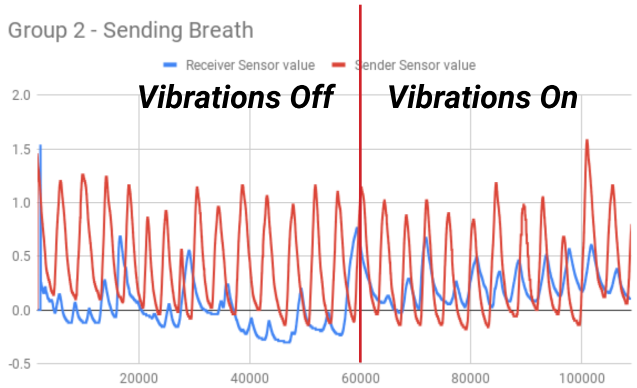


Fig. 63 - Group 2

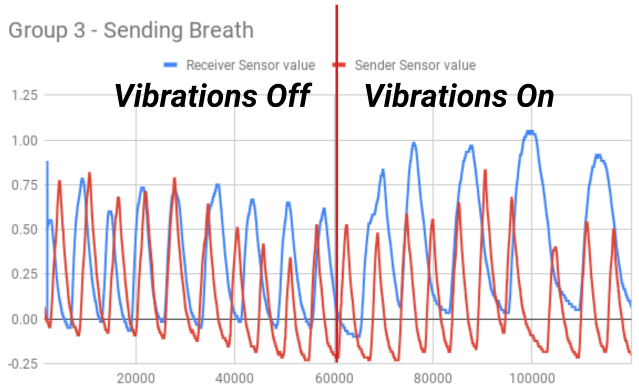


Fig. 64 - Group 3

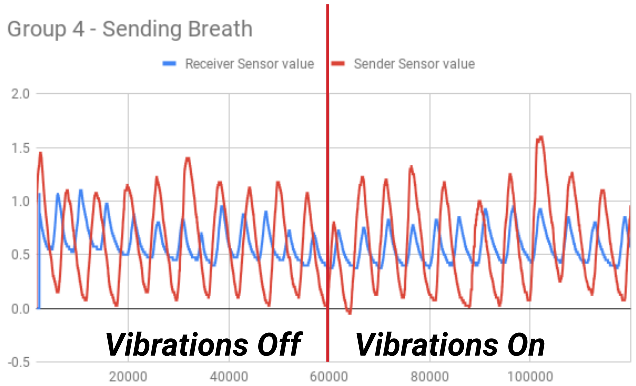


Fig. 65 - Group 4

The results of the form are also more varied. The overall experience was positively rated (7.4/10), with participants describing the experience of feeling another person from a checklist with the terms immersive (75%), intense (50%), pleasant (50%) and unpleasant (50%). Participants that rated it as unpleasant did point out that it was not the word they would use, but that the vibrations were interfering with their focus. The assessment of the aesthetic experience of feeling another person's breath was pleasant (7.4/10), intense (7.2/10) and very interesting (8.6/10) (Fig. 66).

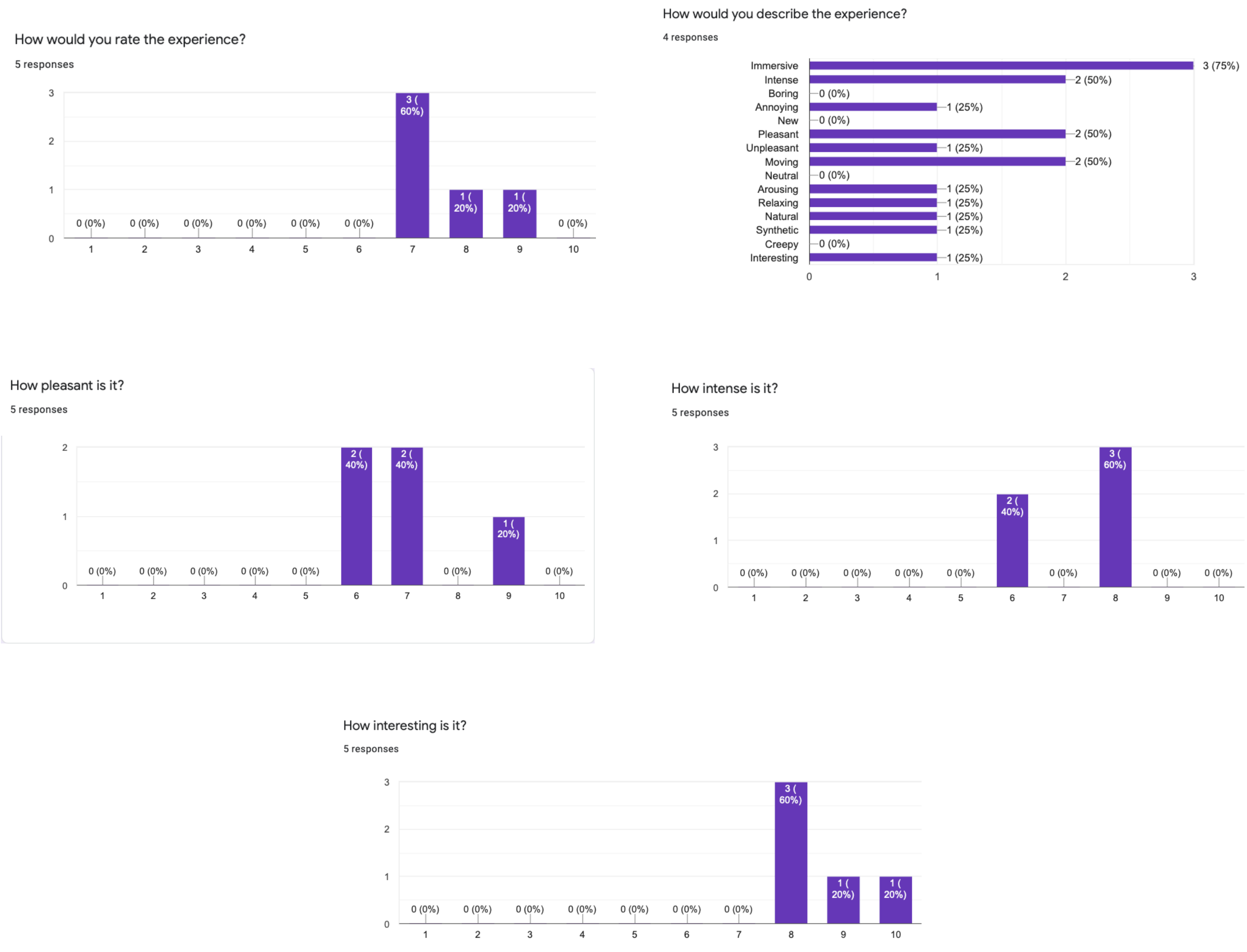
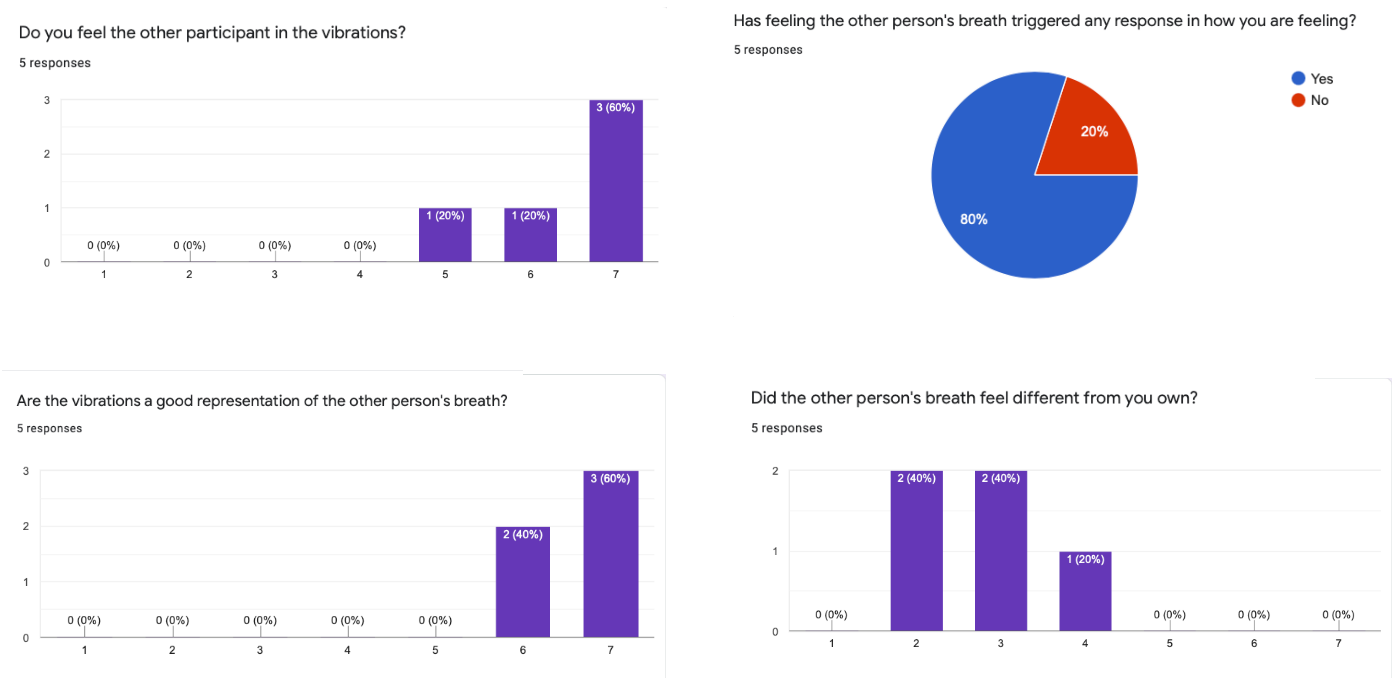


Fig. 66 - Responses to the post-test form of the final experiment - 2

Participants got to really feel the other person in the vibrations (6.4/7), with the vibrations being a really good representation of the breathing of the other person (6.6/7), stating that the breathing of the other person felt moderately different than their own (5.2/7). Participants really got to feel the presence of the other person in the vibrations (6.4/7), with people being able to successfully describe how the other person was feeling from the vibrations they were feeling (100% accuracy), and most of them saying that the breath of the other person had triggered a reaction in them (80% of participants) (Fig. 67). Some of the descriptions were surprisingly concrete and accurate:

> *"In the first 3 min I think she was nervous therefore her breathing was slightly fast. I also think she forced a more intense breathing at some point. During the longer session, she felt still a bit unstable but more calm until I believe some stressing thoughts came to her mind and again she sped up the breath".*

To this the other participant totally agreed with, and said that she was nervous about being sensed, then had drifted into a more focused state until the finishing state, where her focus had diminished at the end of the session.



*Very different is 1, the same is 7, values are inverted in the text

Fig. 67 - Responses to the post-test form of the final experiment - 3

4.3.5. Conclusions

The two tests shine a positive light on the experience of a joint breathing session through vibrations. The main conclusions are the following.

Vibrified breath can create intense emotional interactions between people

One of the parts on which participants agreed more substantially was in the immersiveness, interestingness and the intensity of the interaction. Participants were not left indifferent about the experience and they felt positively about it (Fig. 68).

The descriptions given in the post-test form were:

> *"Breathing gave presence to her, I felt that she was standing in front of me, or at least I was visualising that."*
>
> *"Engaging and interesting, as mentioned, it is intriguing to connect with someone via such a way."*
>
> *"I just tried to be present, understanding how she was feeling. I also had a really beautiful sensation when I managed to harmonize (2 breaths of her - 1 of mine) because I was feeling connected."*

The feelings of presence and synchronisation have been studied in the past and are very significant for human interaction, so it may be interesting to study the possibilities of Vibrified biofeedback to achieve this in a mediated way (Gill, 2007). The obtained findings do demonstrate that it is possible to capture the biosignals, represent it through haptics and use it to create an engaging and meaningful interaction.

Fig. 68 - Participants discuss their experience during the post-session interview

Vibrified breath can transmit emotions and trigger empathetic responses

After analysing the accuracy of the interpretations of the other participant's breath, it was surprising how some of the descriptions were really accurate and specific, and how all of them seemed to be accurate depictions of what the participants were feeling. Some participants were able to interpret how the other was feeling to a really accurate level.

The vibrations were considered a good representation of breath, so it seems that Vibrified breath is a good way of getting insight into one's inner state (Fig. 69). It also triggered a reaction in the participant receiving the Vibrified breath, with different reactions to the stimuli. The final interaction concept then elicited an emotional response and triggered a reaction in the person receiving the vibrations, which responds to one of the research questions for this last test, and was one of the most important aspects of the final prototype: Vibrified breath can transmit the inner state of people, can elicit emotions and trigger empathetic responses.

However, it is easy to relate a breathing pattern to breath, so it is easy to attribute it to another social actor. This opens other questions, like what would the effects be of Vibrified biofeedback that is not as straightforward to understand or with signals that do not correspond to aesthetically pleasant vibrations patterns.

Fig. 69 - One of the participants adjusts the volume of the vibrations during the "Feeling Yourself" adaptation stage

We have designed a transparent interface

One of the questions that was most interesting was one asked in the interview after the test, in which participants were asked if while breathing and feeling themselves, they were focused on modulating their breathing, or if they were concentrating on the vibrations and how they felt. The responses were varied, but none were concentrating on the vibrations, rather they explained that the vibrations were representing the breath, or that they were helping them to focus on the breathing.

Only one of the participants focused on the vibrations, but she used them to help her imagine a charge of negativity that she could then exhale. There is a big difference with, for example, the enactive torch. The participants in this case did not focus on the use of the tool, in this case the sensor, but because the sensor was acting as a passive element that participants did not experience, they just got to feel the stimuli (Fig. 70).

> *"I was visualising that the vibes were a way of charging my chest of negativity, stress, etc and when I exhale, I was releasing all that tension. They were physically going away, so that was an extremely powerful sensation for me."*

The stimuli also seemed to be well adjusted to the interaction, as it came from the experiential workshop conducted previous to the test. Vibrations were found to be relaxing and immersive, and when they were found slightly annoying, was when the vibrations were shared to the participant and they did not align with their own breathing pattern.

Enactive interfaces are defined by Froese et al. (2012) as "technological interfaces that are designed for the purpose of augmented sense-making". The presented interface fits into this description, as it allows participants to access new layers of information within the interaction, and therefore open a new avenue for communication.

Fig. 70 - Participants after the first "Sending Breath" stage of the session

Unlike the Enactive Torch, participants were not concerned with the operation of the sensor, as it worked seamlessly with actions that they naturally performed during the interaction, the interaction was the only thing that they experienced. This was one of the reasons why biofeedback was chosen for the interaction.

When feeling the other participant, some of the participants responded that they got to feel the other participant's presence through the vibrations, instead of only vibrations. This means that even the vibrations which are not related to their own breathing are not seen as random, but attributed to the other.

Using the haptic vibrations proved to also be a correct decision, as the peripheral and non-disruptive nature of this modality allowed people to concentrate on the breathing, allowing them to close their eyes and "zone out the real world and relax much more". Therefore, the Vibrification of biofeedback shows promise as a way of creating interactions that allow participants to focus on experiencing the world and create emotion eliciting feedback that can be experienced by one-self or with others.

4.3.6. Limitations

Due to technical and time reasons, there were limitations to what could be studied in this test. First, participants were not isolated and did interact before the start of the procedure, so they were fully aware of who to attribute the vibrations to. Isolating the participants during the procedure was a whiteboard between them. Facilities where participants get to be isolated before and during the whole procedure could better test the attribution of the vibrations and could change the perception of the vibrations.

The way of attaching the actuators to the body was also less than ideal, as the bandages used could hardly hold the Puck transducers (Fig. 71). This meant that the set up was not ideal, but due to time constraints, making a system to hold it was not a possibility. A better system to hold the actuators could improve the quality of the contact of the actuators.

Finally, the data processing was far from ideal due to a bug that stopped recording the values of the sensors after random amounts of time in the software. The quantitative data lost in the recording could have shone more light on the physical reaction of the participants, but the data available was enough to draw conclusions in this study.

Fig. 71 - Participant holding the transducer to his chest to avoid it falling

5. Beyond Graphical Interfaces

5.1. Discussion and Reflections on the Project

In the current state of the art of digital design, interfaces are designed to be delightful while being used and experienced. At the end of the day, they are the only way to use our devices in a world where technology is getting more and more abstracted and immaterial. Entire disciplines are dedicated to creating these interfaces, focusing on making them as good as they can be.

For certain tasks, this is necessary and convenient, while for others it is less than ideal. One of those cases is interpersonal communication, where technology is allowing us to open new channels to connect with each other via instant texting, chatrooms, video calls and live streams. The prioritisation of visual displays and technology has trapped interactions within screens and has prioritised the exchange of information over other parts of human interaction.

This project is part of a shift that is happening in design for interaction, one that shows interests in exchanges that do not focus on purely trading information between individuals, but wants to take digital technology one step further and allow it to do things that were not possible until now. Things that are part of human experience as much as having a conversation, like emotional social interaction (Fig. 72).

To do so, new kinds of interfaces and ways of capturing and conveying information have to be developed. All of them with their set of challenges and difficulties, as the nature and requirements of the interactions are different from what designers have been focusing until now.

Fig. 72 - Another example of an interaction which is not suitable to be replicated through the current digital interfaces

5.1.1. Emotional Interaction through Haptic Vibrations

The main goal of this project was to create an emotional and engaging interaction by capturing and sharing human experience through haptic vibrations, and the results are really promising. The result ended up being a prototype that showcased the possibilities of haptic displays and Vibrification of biofeedback as a space for exploration and future product development.

Vibrification allowed the transformation of biosignals into emotion eliciting VTS. To test this, an experiment was carried out where participants shared their breath, a signal similar to haptic patterns found pleasant in past research and that could be related to intimate interaction, in a joint breathing session.

The results were really positive. And this shows us that the use of Vibrified biofeedback could be used in the future to create VTS that can help to create interactions that were impossible with mainstream digital technology. Think on the interactions when people feel each other breathe, like hugs, laying together or sex. All are powerful and intimate, and Vibrified breath could bring a small part of this power to future digital interactions.

Vibrified breath also makes good use of the capacity of haptic vibrations to represent other people's presence. The participant feeling the Vibrified breath felt the presence of the other participant in the vibrations, the breath feeling different from their own and shifting during the sessions, making clear that there was indeed another person to attribute the signal to.

Not only that, but Vibrification showed that participants could feel what the other was feeling, and that there was an empathetic response to the vibrations. Participants felt the other distressing and unfocusing when the breath pattern changed, or relaxed when the other person was just breathing regularly.

This implementation of the prototype and the concept of Vibrification was very simple and basic exploration of a design space, and different directions could be explored in the future. There are a myriad of applications possible only for breathing (therapy, meditation, sleep…), and a lot of different biosignals to be vibrified (brainwaves, heart rate, movement…).

As stated in chapter 1, at the beginning of this project we set ourselves the goal to bring us closer to digital hugs, and with our results, I think we did.

5.1.2. Reciprocity in Interaction - the Key to Participatory Sense-Making

Many of the ideas that emerged during the project were left in the table due to time or technical constraints. The main and a very significant one for the project was to make the last test a reciprocal interaction. During the sending breath part of the experiment the interaction was one-directional. However, participatory sense-making requires an open channel to allow both actors to communicate, so we did not get to test augmented participatory sense-making through Vibrified biofeedback.

There is a reason for this. For the final test, two hypotheses could have been tested: that Vibrifried breath could elicit emotion and allow participants to understand the emotional state of the other, or that Vibrified breath is suitable to create a two-way channel for interaction and participatory sense-making. The first hypothesis was prioritised.

To allow participants to better concentrate on what they were feeling and on breathing, one of them was allowed to breathe without sensing the other's breath and therefore, made the interaction go only in one direction. This helped prove that it is indeed possible to understand the emotional state through Vibrified breath, that this caused an empathetic response in the receiver of the breath, and that it is intense and immersive to experience it.

What was tested in the final experiment was augmented sense-making through Vibrification, and the results also showed that technology in this case helped participants to focus on their breaths, to relax and to immerse in the breathing session.

It would indeed be possible to create a reciprocal interaction between participants similar to what Baldi et al. (2020) did with the social walking experiment, and see how participants react to each other's breath. This was not tested due to time constraints in the project, and adding an extra part to the experiment would have made the session too tiresome for the participants.

Making the vibration reciprocal brings many interesting challenges to the interaction. The most important one being if just feeling the other participant's breath is enough, or if it is necessary to transmit information about one's breathing as well, what variable of the waveform could be mapped to achieve this and what the effects of this would be.

The concept that was designed for this was to use incident waves, similar to the ones used in experiment 2, to signal the offset between both participants' breath. This idea was not put to test, however, with difficulties in defining the polarity of the stimulus and with feedback needed in order to make a final test setup.

Haptic displays with matrices of actuators could also allow signals to move through the body, something that participants in the workshop suggested in order to overcome some of the limitations that they found. Effects called phantom vibrations have proven to create the illusion of movement between vibrators and could be exploited in a more complex prototype (Kim et al., 2020).

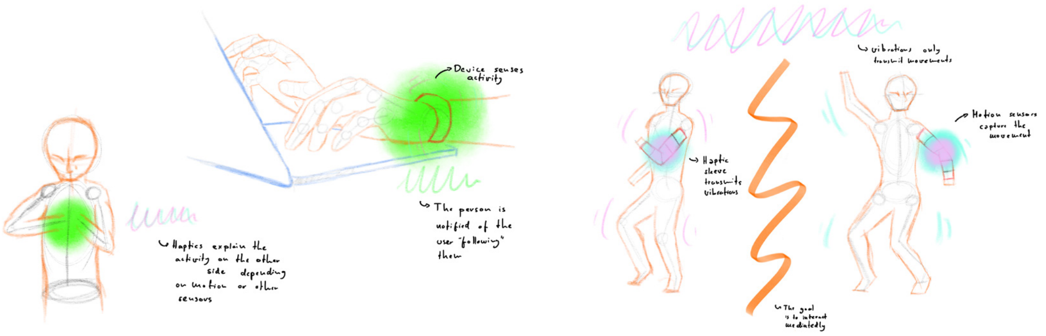


Fig. 73 - Two concepts that use movement to create an interaction between people, one to keep in touch, the other to dance

Still this remains a question, how to create waveforms to make a two-way Vibrified interaction. This will prove to be a very important next step in the field of Vibrification and interaction through haptic vibrations.

5.1.3. New Inputs for Vibrification

Breathing was a good point to start the exploration of Vibrification for how easy it is to relate to an up-and-down pattern to the action of breathing. It is also a tactile experience common to everybody and easily recognisable. Heartbeats are also a good example of this for the same reasons, and Macdonald et al. (2020) found that participants could easily recognise a heartbeat in a tactile format.

This may change with other kinds of Vibrified data, like brain waves and body movements, or when waveforms and vibration patterns need to get more complex to accommodate certain kinds of interactions. This would be a natural evolution of Vibrification, and is a challenge that will have to be addressed in future research.

Here is where participatory sense-making could be a decisive factor. As seen in experiment 2, participants interacting and exchanging information during the interaction in order to understand how each other interpreted different signals and reaching an agreement made all the difference in understanding the vibration signals. With an abstracted and more difficult to interpret stimulus, having a social actor to participate in the interaction could also prove to be useful.

The meaning of the different vibrations and parameters on the waveform were found to be emergent during the interaction, so it may be interesting to see how different social actors come together to make sense of the interaction through the vibration signals. The key would be to be able to attribute the signals to what social actors are doing in order to create the feedback loops and allow the participatory sense-making process to happen.

After the Hands on Vibes workshop (see chapter 4.1), having sessions similar to that one to let people experiment, build and explore seems to be a great activity to better understand the perception of haptics for social interaction. The challenge in this case is how difficult it is to get people to conduct exploration activities in HaXD. Creating more complex and abstract patterns requires a more complex backend, which makes it exponentially difficult to involve new people in the exploration (Fig. 74).

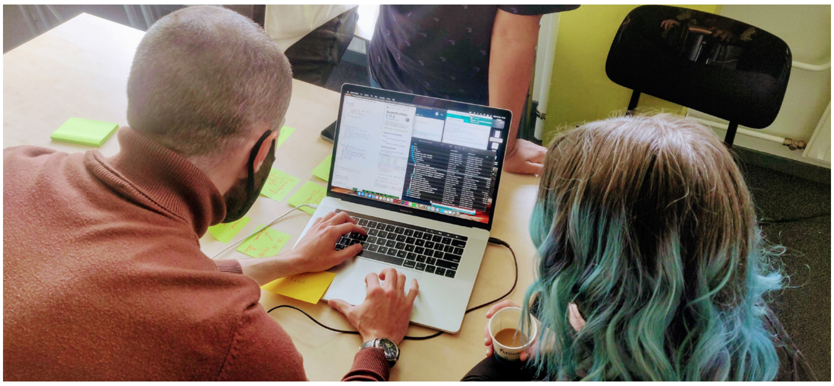


Fig. 74 - Having to deal with technical difficulties during the workshop was the main challenge

5.1.4. Designing for Haptic Designers

Finally and a bit off-topic, it seemed important to reflect on one of the most challenging parts of this project. Camille Moussette (2012), Oliver Schneider et al. (2017) made echo of the problem of the accessibility of haptic design. Both discuss how these are the early steps of the field that is quickly gaining momentum. I also had a chat with a fellow haptic designer at Umeå Institute of Design, Thomas Müller (2020), who encountered exactly the same problem during his graduation.

After conducting the Hands on Vibes (see section 4.1), there is solid evidence that there is great potential in being able to quickly build, deploy, experience and iterate haptic based interfaces, but the nature of the hardware and software make it impossible to conduct workshops, testing or guerrilla testing easily. Those processes are crucial in the development of User Experience (UX) Design and the fact that they are not available for haptic designers is something that will make the field lag until this is fixed.

The field of haptics was revolutionised by engineers jumping into it and making it interdisciplinary (Moussette, 2012). Designers joining the field, designing and experimenting with implementations, gathering user data and conducting design research will most likely prove to be a great step in the development of haptics as an interdisciplinary and user-facing field.

During this project, making haptics accessible for people to explore and participate in the experiments was a significant challenge to overcome, having to orchestrate different pieces of software, sensors and communication protocols (Fig. 75).

The conception of Playgrounds (see section 3.2) as a “modular” system to create interfaces was crucial to allow the experimentation to happen, but it was still limited to the use of graphic interfaces. Take a moment to reflect on the software involved: an OSC interface made to create and control music (touchOSC), a sketching programming language used for visual arts (Processing) and a platform for real life audio synthesis (SuperCollider).

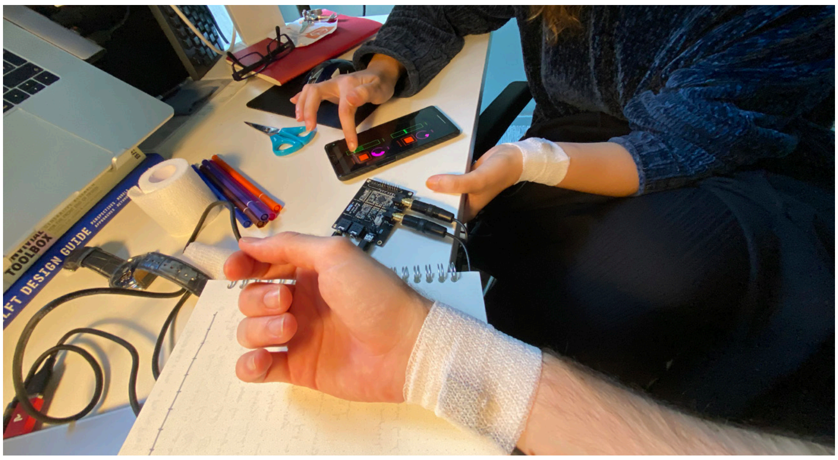


Fig. 75 - Playgrounds had to be developed with an app designed to make music

Tools for haptic designers are not non-existent, though. Lofelt, the company developing the L5 actuators used in this research has their LoFelt Studio software to develop software to create haptic vibrations for iPhone. Apple also has Core Haptics, an entire platform dedicated to their Taptic Engines in their devices. Teenage Engineering developed a rumble pack for their OP-Z synth in conjunction with LoFelt to create bass vibrations. All of those solutions are limited in their scope and application range, and stepping out of their implementations leaves designers in the difficult position of having to develop their own tools.

As Thomas *Müller* found in his Master Thesis *Designing with Haptic Feedback* (2020) from interviews with experts in the field from different companies:

> *"There are little to no guidelines available, and the complexity makes it hard to get started and work with it in professional life" (Müller, 2020, pp.62)*

If designers, with limited technical knowledge and understanding like myself, are to be involved in the future of the field of haptics, it will require designing for haptic designers (Fig. 76)

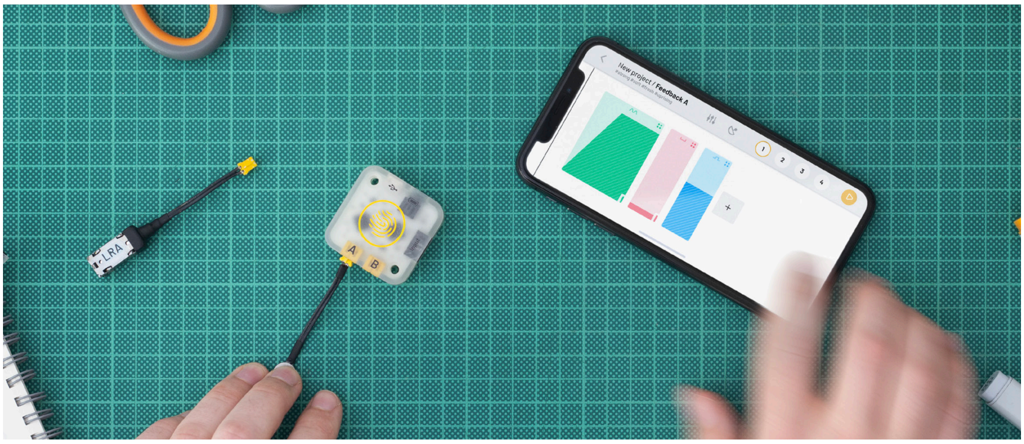


Fig. 76 - Müller developed a toolkit for rapid haptic prototyping (Müller, 2020)

5.2. A Personal Note

This part will be dedicated to a reflection on this journey that started a bit more than a year ago, into the world of haptics and design for interaction. As mentioned in the foreword, this project has taken me to places that I never thought I would ever go. There have been significant challenges in the way also at a personal level.

5.2.1. Exploring vs. Performing

As a person a bit obsessed with performance, embarking on a journey that required exploration more than results has proven to be quite a challenge. Doing the experiments, exploring the Vibrification space, organising the workshop and programming, everything had to be working and perfect, and sometimes it is necessary to change the mindset and relax a bit.

Some of the best moments of the project, like the Hands on Vibes workshop, were when I relaxed and let go. Getting to that point is very important for designers to get to, when we have to relax and look at things from the angle of exploration and learning rather than performing. I would say that during this project, I have made some progress in this regard, and I am happy to see that the results of doing so were key to the final outcome.

5.2.2. Reflection, Ownership and the Big Picture

Reflecting on the roots of my motivations and why I do what I do has also been a big challenge of this project. Several times through the projects I have been so obsessed about the micro level of it all, entangled in the technical aspects, the metrics and the literature, that I could not see the forest for the trees.

Especially when showcasing my work or explaining what the project was about, I found myself so deep in the complexity of it all that I was unable to find words for what I was doing, even to myself. Pushing me to abstract myself from the immediate work and survey the big picture proved to be very difficult.

This was made more difficult by a variety of facts. First, that this project came from previous work and it sometimes felt like I was being dragged more than owning the project. Second, I was (and still am) not confident in my knowledge of haptics, or cognition for that matter. And third, that I was working with people who have strong visions and opinions which sometimes I felt were more relevant than my own.

My supervisory team had to really pressure me to reflect on why I was doing this project, and finding the meaning of it all since the beginning of Sweet Sensations. And it was with a really inspiring phrase that I would like to share that I got to really reflect on what I had been doing:

> *"Everyone has their approach to a topic, I have mine, the other supervisors have their own, and we see in haptics something of our own. Your take is totally different from mine, your story is unique to you and that is what makes your contribution to the field unique. And that story, not only this project, but since the time you started to work with me, is what you have to tell."*

These may not be the exact words, but the message was that one. Taking time to reflect on why this project was difficult, but really helped me when communicating the results and reflections on the project.

5.3. Conclusion

This project was meant to explore social connection between people through haptic interfaces based on tactile vibrations, but it ended up being a reflection on how technology has been influenced by our understanding of human cognition and how new trends in cognitive science can help to create interfaces that make our digital interactions emotional, rich and engaging.

It started with an open and experimental approach to the space, which helped to understand processes of participatory sense-making through tactile vibrations and the usage of haptic vibration interfaces for communication. This shaped the image and set foundations of what was possible to achieve as a final interaction.

The result was an interface that allowed people to emotionally connect using their breath as an input to create haptic vibrations. To do so, a new concept called Vibrification was used, a technique inspired by Sonification that transforms data, in this case biosignals, into tactile vibrations. We successfully tested that Vibrified biosignals are an input that participants perceived as emotionally intense and that allowed them to react and feel the other's presence.

During the tests, the vibrations helped participants to concentrate on the breathing exercise and created an immersive and intense interaction with themselves and each other. The experience was highly rated and participants praised the interface in helping them to feel their breath when they were feeling themselves, and eliciting an emotional and empathetic response when feeling each other.

Most of the technology and development was done in house, developing sensors, designing interfaces and programming software that allowed the experiments to happen.

This is the main contribution of this project, in the search for emotional social interaction, we propose a new way to design for haptic interaction. Vibrification of biosignals is a new approach that enables us to capture and share human experience to design new ways in which to emotionally connect through technology, inspired by the wide range of possibilities that we, as humans, have to experience the world, ourselves and each other.

6. References

Abraham John A. (2021), *Project Vital Presents Spiritus: Designing a Data Supported Breath Practice for a TU Delft Student's Journey Towards Inner Peace,* (Dissertation), retrieved from: http://resolver.tudelft.nl/uuid:1b54aaf2-7144-4f0f-ad72-88a309540d20

Altozano J. (2017), El Señor de los Anillos – Análisis de la Banda Sonora (Comunidad) [video], YouTube, https://youtu.be/y5LLHZf9ebU

Arnold R. (2020), PLAY ME: interactive sonification of sexual arousal in long-distance relationships, Paladyn, Journal of Behavioural Robotics, pp. 250-70

Anderson M., (2003), Embodied Cognition: A Field Guide

bHaptics, *TacSuit X40*, retrieved from: https://www.bhaptics.com/tactsuit/tactsuit-x40

Baldi T. L., Paolocci G., Barcelli D., Prattichizzo D., (2020), Wearable Haptics for Remote Social Walking, IEEE Transactions on Haptics, Vol. 13, Issue 4

Berlyne, D. E. (1970). Novelty, complexity, and hedonic value. Perception & psychophysics, 8(5), pp. 279-86.

Björnsdotter, M., Löken, L., Olausson, H., Vallbo, ., Wessberg, J., (2009), Somatotopic organization of gentle touch processing in the posterior insular cortex, The Journal of Neuroscience 29(29), pp. 9314 – 20

Choi, S., Kuchenbecker, K.J. (2013). Vibrotactile display: perception, technology, and applications. Proc. IEEE 101 (September (9)), 2093–2104

Clark A. (1996), Being There, MIT Press, Cambridge, MA

De Jaegher H., Di Paolo E., (2007), Participatory sense-making: An enactive approach to social cognition, Phenomenology and the Cognitive Sciences, vol. 6, pp. 485–507

Dobson K., Boyd D., Ju W., Donath J., Ishii H., (2001), Creating visceral personal and social interactions in mediated spaces, CHI EA '01: CHI '01 Extended Abstracts on Human Factors in Computing Systems,, pp. 151–152

Drescher V. M., Gantt W. H., Whitehead W. E., (1980), Heart rate response to touch, Psychosomatic Medicine, vol. 42, no. 6, pp. 559 - 65

Froese T., McGann M., Bigge W., Spiers A., Seth A. K. (2012), The Enactive Torch: A New Tool for the Science of Perception, IEEE Transactions on Haptics, Vol. 5, No. 4, pp. 365 - 75

Gemperle F., Hirsch T., Goode A., Pearce J., Siewiorek D., Smailigic A. (2003), Wearable vibro-tactile display

Giaccardi E., Stappers P. J. (2017), Research through Design, The Encyclopedia of Human-Computer Interaction, The Interaction Design Foundation

Gill S. P. (2007), Entrainment and Musicality in the Human System Interface, Springer-Verlag London Ltd.

Guéguen N., Jacob C., (2005), The effect of touch on tipping: an evaluation in a french bar, International Journal of Hospitality Management, vol. 24, no. 2, pp. 295 – 99

Guéguen N., Jacob C., Boulbry G., (2007), The effect of touch on compliance with a restaurant's employee suggestion, Interna- tional Journal of Hospitality Management, vol. 26, no. 4, pp. 1019 – 23

Hasegawa H. Okamoto S., Ito K., Yamada Y (2019), Affective Vibrotactile Stimuli: Relation between Vibrotactile Parameters and Affective Responses, Transactions of Japan Society of Kansei Engi

Havelange V., (2010), The Ontological Constitution of Cognition and the Epistemological Constitution of Cognitive Science: Phe- nomenology, Enaction, and Technology, Enaction: Toward a New Paradigm for Cognitive Science, J. Stewart, O. Gapenne, and E.A. Di Paolo eds., pp. 335-360, The MIT Press

Hermann, T., Hunt, A., Neuhoff, J. G., editors (2011). *The Sonification* Handbook. Logos Publishing House, Berlin, Germany.

Hern A. (2021), Facebook sets out plan for 'effortless' virtual reality socialising, The Guardian, retrieved from https://www.theguardian.com/technology/2021/mar/10/facebook-sets-out-plan-for-effortless-virtual-reality-socialising

Huisman, G. (2017), Social Touch Technology: A Survey of Haptic Technology for Social Touch, IEEE Transactions on Haptics

Huisman, G., Frederiks, A.D., van Erp, J.B., Heylen, D.K., (2016) Simulating affective touch: Using a vibrotactile array to generate pleasant stroking sensations. International Conference on Human Haptic Sensing and Touch Enabled Computer Applications; Springer:Cham, Switzerland, pp. 240 – 50

Huisman G., Frederiks A. D., Van Dijk B., Heylen D. K. J., Kröse B., (2013), The TaSST: Tactile Sleeve for Social Touch, IEEE World Haptics Conference

Huisman G., Frederiks A. D., Van Erp J. B. f., Van Dijk B., Heylen D. K. J. (2016), Simulating Affective Touch: Using a Vibrotactile Array to Generate Pleasant Stroking Sensations, Conference: International Conference on Human Haptic Sensing and Touch Enabled Computer Applications

Hutchins E., (2010), Enaction, Imagination, and Insight, Enaction: Toward a New Paradigm for Cognitive Science, J. Stewart, O. Gapenne, and E.A. Di Paolo eds., pp. 425-450, The MIT Press

Jones, L. (2018), Haptics, The MIT Press Essential Knowledge Series

Kandel, E.R., Schwartz, J.H., Jessell, T.M., (2000). Principles of Neural Science, 4th edition McGraw-Hill.

Kleinke C. L., (1977), Compliance to requests made by gazing and touching experimenters in field settings, Journal of Experimental Social Psychology, vol. 13, no. 3, pp. 218 – 23

Kramer G., Walker B., Bonebright T., Cook P., Flowers J., Miner N., Neuhoff J., (1999), Sonification report: Status of the field and research agenda, Tech. Rep., International Community for Auditory Display, http://www.icad.org/websiteV2. 0/References/nsf.html

Karuei I., MacLean K. E., Foley-Fisher Z., MacKenzie R., Koch S., El-Zohairy M., (2011), Detecting vibrations across the body in mobile contexts, in Proc. ACM Int. Conf. on Human Factors in Computing Systems, pp. 3267.

Kieliba P., Clode D., Maimon-Mor R. O., Makin T. R., (2021), Robotic hand augmentation drives changes in neural body representation, Science Robotics, Vol. 6, Issue 54

Kim, J., Oh, S., Park, C., & Choi, S. (2020), Body-Penetrating Tactile Phantom Sensations, In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (pp. 1-13).

Klemmer S. R., Hartmann B., Takayama L., (2006), How Bodies Matter: Five Themes of Interaction Design

Kox M., van Eijk L. T., Zwaag J., van den Wildenberg J., Sweep F. c., van der Hoeven J. G., Pickkers P., (2014) Voluntary activation of the sympathetic nervous system and attenuation of the innate immune response in humans, Proceedings of the National Academy of Sciences 111, pp.7379–7384.

Lee J. (2020) A Neuropsychological Exploration of Zoom Fatigue, Psychiatric Times, retrieved from https://www.psychiatrictimes.com/view/psychological-exploration-zoom-fatigue

LoFelt GmbH (2019), L5 Actuator, revision 1.4

Macdonald A. S., Brewster S., Pollock F., (2020), Eliciting emotion with vibrotactile Stimuli evocative of real-world sensations, ICMI '20, The Netherlands

MacLean K. (2003), The impact of institutionalization on child development, Development and Psychopathology, vol. 15, no. 4, pp. 853– 884

Master S. L., Eisenberger N. I., Taylor S. E., Naliboff B. D., Shirinyan D., Lieberman M. D. (2009), A picture's worth: Partner photographs reduce experimentally induced pain, Psychological Science, vol. 20, no. 11, pp. 1316–18

McDermott, J. H. (2021), Auditory preferences and aesthetics: Music, voices, and everyday sounds. Neuroscience of preference and choice, pp. 227 - 56, Academic press

Morrison, I., Löken, L., Olausson, H. (2010), The skin as a social organ. Experimental Brain Research, 204, pp. 305–314

Moussette C., (2012), Simple Haptics: Sketching Perspectives for the Design of Haptic Interactions

Müller, T. (2020). Designing with Haptic Feedback (Dissertation). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:umu:diva-172622

Omni, Omni One, retrieved from: https://invest.virtuix.com

Pallasmaa, J. (2005). The Eyes of the Skin - Architecture and the Senses. Architecture, pp. 80, John Wiley & Sons Limited. Retrieved from https://benv1082.unsw.wikispaces.net/file/view/Eyes of the Skin Part 1.pdf

Peters J. (2021), Hans Zimmer isn't the only composer that can make tech sounds, you know, The Verge, retrieved from https://www.theverge.com/tldr/2021/5/10/22429697/hans-zimmer-bmw-car-driving-noise-other-comporsers

Russell J. A. (1980), A Circumplex Model of Affect, Journal of Personality and Social Psychology, Vol 39, No. 6, pp. 1161 - 78

Sallnäs E. L. (2010), Haptic feedback increases perceived social presence, in Proc. Int. Conf. on Human Haptic Sensing and Touch Enabled Computer Applications. Springer, pp. 178–185.

Schneider O., MacLean K., Swindells C., Booth K. (2017), Haptic experience design: What hapticians do and where they need help, Int. J. Human-Computer Studies 107, pp. 5–21

Scientific Instruments Inc., Stretch SensorTM

SenseGlove, *SenseGlove Nova*, retrieved from: https://www.senseglove.com/product/nova/

Sha X. W. (2002), Resistance is Fertile: Gesture and Agency in the field of responsive media, in makeover: writing the body into the posthuman technospace. Configurations 10(3), pp. 439-72

Shannon C., Weaver W. (1949), Mathematical theory of communication. University of Illinois Press, Urbana, IL

Shor D., Ruitenburg Y., Lomas D., Huisman G. (2021), The Resonance Pod: Applying Haptics in a Multi-Sensory Experience to Promote Relaxation Through Breathing Entrainment

Stewart J. (2010), Foundational Issues in Enaction as a Paradigm for Cognitive Science: From the Origin of Life to Consciousness and Writing, Enaction: Toward a New Paradigm for Cognitive Science, J. Stewart, O. Gapenne, and E.A. Di Paolo eds., pp. 1- 32, The MIT Press

Strong, R., & Gaver, B. (1996). Feather, scent, and shaker: Supporting simple intimacy. In Proceedings of ACM, Conference on Computer Supported Cooperative Work (CSCW '96; pp. 29–30). New York: ACM Press.

Toet, A., Kaneko, D., Ushiama, S., Hoving, S., de Kuijf, I., Brouwer A. M., Kallen V., van Erp, J. B. F., (2018). EmojiGrid: a 2D pictorial scale for the assessment of food elicited emotions. Front. Psychol. 9, 2396

Van der Madden W., Lomas J. D. (2020), Feel the Vibe: the Aesthetics of Whole Body Vibration

Varela F. J., Thompson E., Rosch E. (1991), The Embodied Mind: Cognitive Science and Human Experience, The MIT Press, Cambridge, MA

Vitz P. C. (1972), Preferences for tones as a function of frequency (hertz) and intensity (decibels). Perception & Psychologysics, 11 (1), pp. 84 - 88

Wright M., Freed A., (1997), Open SoundControl: A New Protocol for Communicating with Sound Synthesizers. International Computer Music Conference (ICMC). pp. 101-104

HapSync

Appendix

1. Form - Final Experiment

HapSync - Final Test

*Required

1. What is your participant number? *

2. What is your gender?

   Mark only one oval.

   - Male
   - Female
   - Prefer not to say
   - Other: ______

3. What is your age?

   Mark only one oval.

   - 18-25
   - 26-30
   - 30-35
   - 35-45
   - Over 45

4. Have you participated in one of my previous experiments? *

   Mark only one oval.

   - Yes
   - No

5. What is your previous relationship with the other participant? *

Mark only one oval.

- ( ) We don't know each other
- ( ) We have seen each other around
- ( ) We are friends
- ( ) We are in a relationship

6. How experienced are you with breathing experiences (meditation, yoga, breath therapy)? *

Mark only one oval.

	1	2	3	4	5	
Total Noob	( )	( )	( )	( )	( )	Advanced

Set 1 - Adaptation

7. How would you describe the experience?

Tick all that apply.

- [ ] Immersive
- [ ] Intense
- [ ] Boring
- [ ] Annoying
- [ ] New
- [ ] Pleasant
- [ ] Unpleasant
- [ ] Moving
- [ ] Neutral
- [ ] Arousing
- [ ] Relaxing
- [ ] Natural
- [ ] Synthetic

Other: [ ] ____________________

8. How pleasant is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very unpleasant	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very pleasant

9. How intense is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very bland	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very intense

10. How interesting is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very boring	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very interesting

11. How would you rate the experience?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Extremely negative	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Extremely positive

12. Do you like the position of the actuator in your body?

Mark only one oval.

- ◯ Yes
- ◯ No

13. Any reasons why?

____

____

____

____

____

14. Are the vibrations helping you better sense your own breathing?

Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	They really do

15. Do you think the vibrations are helping you understand your own internal state?*

Mark only one oval.

	1	2	3	4	5	6	7	
They really do not	◯	◯	◯	◯	◯	◯	◯	They really do

Set 1 - Session

16. How would you describe the experience?

Tick all that apply.

- [ ] Immersive
- [ ] Intense
- [ ] Boring
- [ ] Annoying
- [ ] New
- [ ] Pleasant
- [ ] Unpleasant
- [ ] Moving
- [ ] Neutral
- [ ] Arousing
- [ ] Relaxing
- [ ] Natural
- [ ] Synthetic

Other: [ ] ____________________

17. How pleasant is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very unpleasant	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very pleasant

18. How intense is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very bland	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very intense

19. How interesting is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very boring	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very interesting

20. How would you rate the experience?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very negative	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very positive

21. Why?

____

____

____

____

____

22. Do you think the vibrations are helping you better sense your own breathing?

Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	They really do

23. To how extent are the vibrations helping you understand your internal state?*

Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	They really do

24. What terms would relate to the vibrations?

Tick all that apply.

- [ ] Relaxing
- [ ] Stressful
- [ ] Smooth
- [ ] Rough
- [ ] Unpleasant
- [ ] Pleasant
- [ ] Distracting
- [ ] Warm
- [ ] Soothing
- [ ] Painful

Other: [ ] ____________________

25. How useful do you think the vibrations are for this kind of breathing exercise?

Mark only one oval.

	1	2	3	4	5	6	7	
Not useful at all	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Really useful

26. Will you be feeling or breathing in the following set?

Mark only one oval.

⬭ Feeling

⬭ Breathing *Skip to question 50*

Set 2 - Adaptation

27. How would you describe the experience?

Tick all that apply.

- [ ] Immersive
- [ ] Intense
- [ ] Boring
- [ ] Annoying
- [ ] New
- [ ] Pleasant
- [ ] Unpleasant
- [ ] Moving
- [ ] Neutral
- [ ] Arousing
- [ ] Relaxing
- [ ] Natural
- [ ] Synthetic
- [ ] Creepy

Other: [ ] ____________________

28. How pleasant is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very unpleasant	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very pleasant

29. How intense is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very bland	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very intense

30. How interesting is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very boring	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very interesting

31. How would you rate the experience?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very negative	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very positive

32. Why?

____

____

____

____

____

33. Do you feel the other participant in the vibrations?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	I really do

34. Do you think the vibrations are helping you understand the other participant's internal state?*

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
They distract me	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	They really help m

Set 2 - Session

35. How would you describe the experience?

Tick all that apply.

- [ ] Immersive
- [ ] Intense
- [ ] Boring
- [ ] Annoying
- [ ] New
- [ ] Pleasant
- [ ] Unpleasant
- [ ] Moving
- [ ] Neutral
- [ ] Arousing
- [ ] Relaxing
- [ ] Natural
- [ ] Synthetic
- [ ] Creepy

Other: [ ] ______________________

36. How pleasant is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very unpleasant	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very pleasant

37. How intense is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very bland	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very intense

38. How interesting is it?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very boring	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very interesting

39. How would you rate the experience?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very negative	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Very positive

40. Do you feel the other participant in the vibrations?

Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	◯	◯	◯	◯	◯	◯	◯	I really do

41. From what you have felt, how would you describe how the other person is feeling? (emotionally and physically)

42. Was this a correct guess? (ask the other participant)

Mark only one oval.

◯ Yes

◯ No

43. Has feeling the other person's breath triggered any response in how you are feeling?

Mark only one oval.

- ( ) Yes
- ( ) No

44. How important was the fact that it was the breathing of another person?

Mark only one oval.

	1	2	3	4	5	6	7	
Not important at all	( )	( )	( )	( )	( )	( )	( )	Very important

45. How important were the vibrations for this process?

Mark only one oval.

	1	2	3	4	5	6	7	
Not important at all	( )	( )	( )	( )	( )	( )	( )	Very important

46. How would you describe it?

47. Are the vibrations a good representation of the other person's breath?

Mark only one oval.

	1	2	3	4	5	6	7	
Not at all	( )	( )	( )	( )	( )	( )	( )	Absolutely

48. Did the other person's breath feel different from you own?

Mark only one oval.

	1	2	3	4	5	6	7	
Completely different	◯	◯	◯	◯	◯	◯	◯	Completely identical

49. Why were they different? (if applicable)

Thanks for participating!

50. Would you like to do any other comments?

2. Form - Experiment 1

HapSync - Experiment 1: Creating Haptic Patterns

*Required

1. What is your relation with the other participant?

   Mark only one oval.

   - Total stranger
   - I know him, but I've never really talked to him
   - We chat when we meet
   - We are friends
   - We are in a relationship
   - It was you, Mikel

2. What's your participant number?

   ____

How did the test go?

3. How would you define the experience

Tick all that apply.

- [ ] Fun
- [ ] Boring
- [ ] Energising
- [ ] Relaxing
- [ ] Stressful
- [ ] Uninteresting
- [ ] Engaging
- [ ] Pleasant
- [ ] Awkward

Other: [ ] ____________________

4. I really got to feel those sensations we were working with

Mark only one oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Definitely

5. When I was feeling the vibrations, it felt...

Tick all that apply.

- [ ] Pleasant
- [ ] Annoying
- [ ] Intense
- [ ] Neutral
- [ ] Boring
- [ ] Arousing
- [ ] Relaxing
- [ ] Painful
- [ ] New
- [ ] Familiar
- [ ] Natural
- [ ] Synthetic

Other: [ ] ____________________

6. Did you like the process of creating the patterns?

Mark only one oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	It was great

7. Separating interfaces 1 and 2 was a good call

Mark only one oval.

	1	2	3	4	5	
Made no sense	◯	◯	◯	◯	◯	It was great

8. How much did that affect the experience?

Mark only one oval.

	1	2	3	4	5	
Not much	⬭	⬭	⬭	⬭	⬭	A lot!

9. How did you feel about collaborating with other person to co-create the patterns?

Tick all that apply.

- [ ] It was fun
- [ ] It was annoying
- [ ] It was awkward
- [ ] Made it easier
- [ ] Made it more complicated
- [ ] We connected
- [ ] We didn't manage to coordinate

Other: [ ] ________________

10. The interface allowed me to control, explore and experiment easily

Mark only one oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	It was great

11. Why? Ease of use? Too simple? Too complex? Things you would have liked to control?

12. Overall, the test was...

Mark only one oval.

	1	2	3	4	5	
Awful	⬭	⬭	⬭	⬭	⬭	Amazing

13. Did you work with the second version of the interface? *

Mark only one oval.

⬭ Yes *Skip to question 14*

⬭ No *Skip to question 19*

Second interface

14. Which interface helped you express the sensations better

Mark only one oval.

⬭ Interface 1

⬭ Interface 2

⬭ Both were good!

15. Can you elaborate?

16. The complex waveform made the stimuli...

Tick all that apply.

- [ ] More intense
- [ ] Annoying
- [ ] More pleasant
- [ ] More arousing
- [ ] More expressive
- [ ] Interesting
- [ ] Uninteresting
- [ ] Louder
- [ ] Too complex

17. Compared to the first interface, this one made it easier to express the prompts

Mark only one oval.

	1	2	3	4	5	
Not at all, first one was better	◯	◯	◯	◯	◯	It made it better!

18. Can you please tell us why?

Now about the Technicalities

19. Instructions were clear and easy to follow

Mark only one oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	Strongly agree

20. The adaptation time was helpful (free play time to see how the interface works)

Mark only one oval.

- ⬭ Didn't really help
- ⬭ Very convenient
- ⬭ Would have liked some more time

21. The control interface was easy to use

Mark only one oval.

	1	2	3	4	5	
Too complicated	⬭	⬭	⬭	⬭	⬭	Good job Mikel!

22. Did the interface allow enough exploration and freedom?

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Other: ____________________

23. Anything that we can improve?

24. The email invite was clear and helpful

Mark only one oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Strongly agree

25. Anything I could get better?

26. The room was a nice environment for the experiment

Mark only one oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	Strongly agree

27. Would you be up to participate in further experiments down the line?

Mark only one oval.

⬭ Yes

⬭ No

28. Is there anything else you would like us to know?

3. Form - Experiment 2

HapSync - Experiment 2: Haptic Charades

1. What is your relation with the other participant?

   Mark only one oval.

   - Total stranger
   - I know him, but I've never really talked to him
   - We chat when we meet
   - We are friends
   - We are in a relationship
   - It was you, Mikel

2. What's your participant number?

   ____

How did the test go?

3. How would you define the experience

   Tick all that apply.

   - [ ] Fun
   - [ ] Boring
   - [ ] Energising
   - [ ] Relaxing
   - [ ] Stressful
   - [ ] Uninteresting
   - [ ] Engaging
   - [ ] Pleasant
   - [ ] Awkward

   Other: [ ] ______________________________

4. I really got to feel those sensations we were working with

Mark only one oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	Definitely

5. When I was feeling the vibrations, it felt...

Tick all that apply.

- [ ] Pleasant
- [ ] Annoying
- [ ] Intense
- [ ] Neutral
- [ ] Boring
- [ ] Arousing
- [ ] Relaxing
- [ ] Painful
- [ ] New
- [ ] Familiar
- [ ] Natural
- [ ] Synthetic

Other: [ ] ____________________

6. The interface allowed me to control and explore the features easily

Mark only one oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	It was great

7. Why? Ease of use? Too simple? Too complex? Things you would have liked to control?

8. How would you rate the location of the actuator? Was it located in a good spot?

Mark only one oval.

	1	2	3	4	5	
Not good	⬭	⬭	⬭	⬭	⬭	Very nice!

9. Are you curious on any positions that you think could be interesting?

Tick all that apply.

- [ ] Neck
- [ ] Shoulders
- [ ] Chest
- [ ] Hand (palm)
- [ ] Lower back
- [ ] Legs
- [ ] Head
- [ ] An external object to touch or grab

Other: [ ] ______________________

10. Why is that?

____
____
____
____
____

11. Overall, the test was...

Mark only one oval.

	1	2	3	4	5	
Awful	◯	◯	◯	◯	◯	Amazing

About the Interaction - Guessing

12. How difficult did you find to guess the correct answer?

Mark only one oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult!

13. How much do you think having a view of the other person helped you guess what they transmitting?

Mark only one oval.

	1	2	3	4	5	
Not much	◯	◯	◯	◯	◯	A lolt!

14. What do you think you missed the most when you couldn't see the other person?

Tick all that apply.

- [ ] Nothing, It did not affect me
- [ ] Nothing in particular
- [ ] Facial expression
- [ ] Gestures
- [ ] Body position
- [ ] Hand movements
- [ ] Their use of the interface
- [ ] The other person exploring to find the correct vibration (before finding the correct one)
- [ ] How the other person used the interface

Other: [ ] ____________________

15. What helped you most when trying to guess the prompts?

Tick all that apply.

- [ ] Ups & Downs
- [ ] Frequency (pitch)
- [ ] Volume
- [ ] Body language and facial expressions
- [ ] How the other person used the interface

Other: [ ] ____________________

16. How do you feel about playing with other person?

Mark only one oval.

- ⬭ It was fun
- ⬭ It was awkward
- ⬭ it was annoying
- ⬭ I didn't like it
- ⬭ We connected
- ⬭ We didn't manage to coordinate
- ⬭ Other: ____________________

17. Out of 5, how did you like the guessing part?

Mark only one oval.

	1	2	3	4	5	
Not fun	⬭	⬭	⬭	⬭	⬭	I really liked it!

About the Interaction - Transmitting

18. How difficult was to make the vibrations?

Mark only one oval.

	1	2	3	4	5	
Very Easy	⬭	⬭	⬭	⬭	⬭	Very Difficult!

19. Were emojis a good idea for this?

Mark only one oval.

	1	2	3	4	5	
They were great!	◯	◯	◯	◯	◯	It made things difficult

20. Why do you think that is?

21. Was the interface right for the task?

Mark only one oval.

	1	2	3	4	5	
Not good...	◯	◯	◯	◯	◯	Very nice!

22. Did you miss any features on the interface?

23. What do you think it helped you to define the vibrations more?

Tick all that apply.

- [ ] Ups & Downs
- [ ] Frequency (pitch)
- [ ] Volume

Other: [ ] ____________________

24. Did you take the other person's input into account when controlling the vibrations?

Mark only one oval.

( ) Yes

( ) No

25. What have you taken into account? Could you elaborate?

____

____

____

____

____

26. Out of 5, how did you like the generating part?

Mark only one oval.

	1	2	3	4	5	
Not fun	( )	( )	( )	( )	( )	I really liked it!

27. Did you participate in the previous experiment in which we created envelopes?

Mark only one oval.

- ( ) Yes *Skip to question 32*
- ( ) No

Comparing with the first experiment

28. Do you think that the continuous vibrations in this experiment helped you express bett than last time?

Mark only one oval.

	1	2	3	4	5	
Not really	( )	( )	( )	( )	( )	Absolute game changer

29. "This interface was better than the last one!"

Mark only one oval.

	1	2	3	4	5	
I extremely disagree	( )	( )	( )	( )	( )	I extremely agree

30. In what sense?

31. How would you describe this new playground interface/interaction?

Tick all that apply.

- ☐ More interactive
- ☐ Less interactive
- ☐ More annoying
- ☐ More pleasant
- ☐ Pretty similar
- ☐ More difficult
- ☐ Simpler
- ☐ Confusing

Other: ☐ ____________________

Now about the Technicalities

32. Instructions were clear and easy to follow

Mark only one oval.

	1	2	3	4	5	
Not at all	○	○	○	○	○	Strongly agree

33. The adaptation time was helpful (free play time to see how the interface works)

Mark only one oval.

- ○ Didn't really help
- ○ Very convenient
- ○ Would have liked some more time

34. The control interface was easy to use

Mark only one oval.

	1	2	3	4	5	
Too complicated	◯	◯	◯	◯	◯	Good job Mikel!

35. Did the interface allow enough exploration and freedom?

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Other: ______________________

36. Anything that we can improve?

____

____

____

____

____

37. The email invite was clear and helpful

Mark only one oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Strongly agree

38. Anything I could get better?

39. The room was a nice environment for the experiment

Mark only one oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	Strongly agree

40. Would you be up to participate in further experiments down the line?

Mark only one oval.

- ⬭ Yes
- ⬭ No

41. Is there anything else you would like us to know?

4. Conceptualisation Sketches

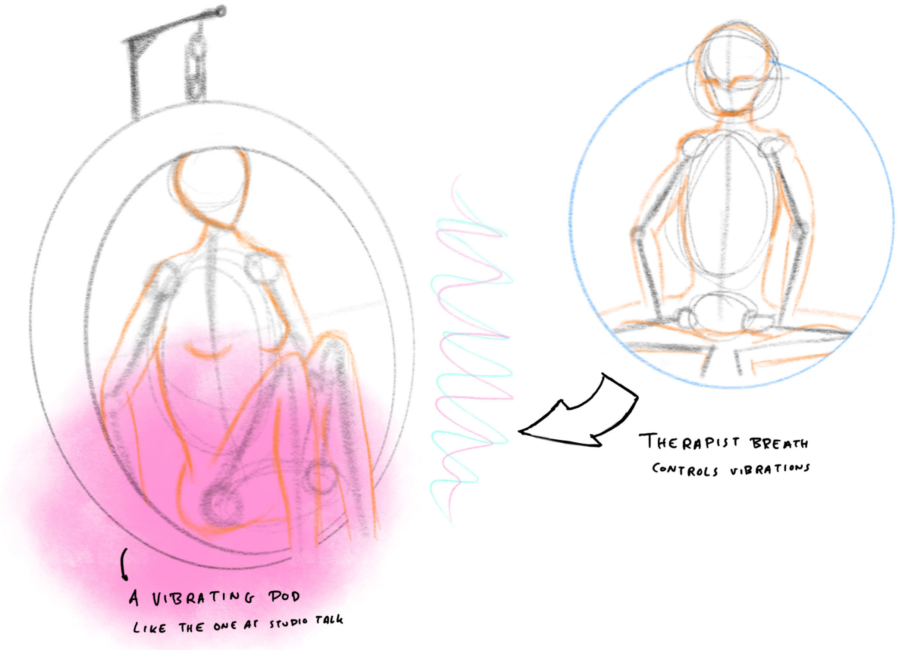


Fig. 77 - The breathing pod, for a participant to have a whole body experience the breathing of a therapist

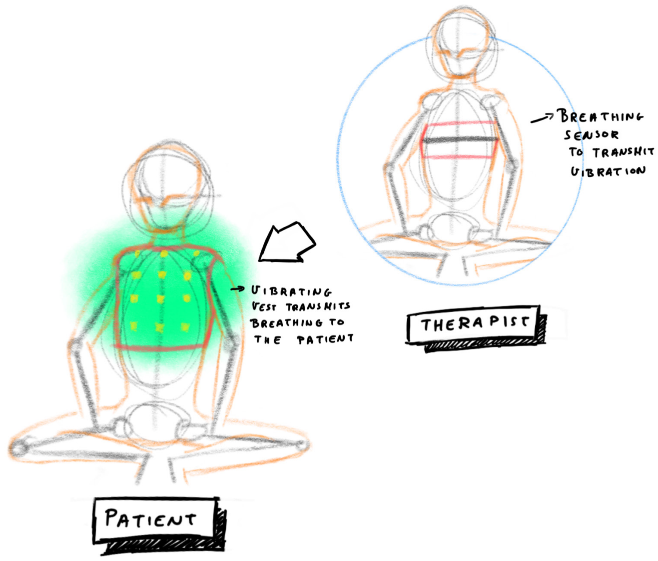


Fig. 78 - Breathing vest, to feel in the torso the breathing pattern of a guide

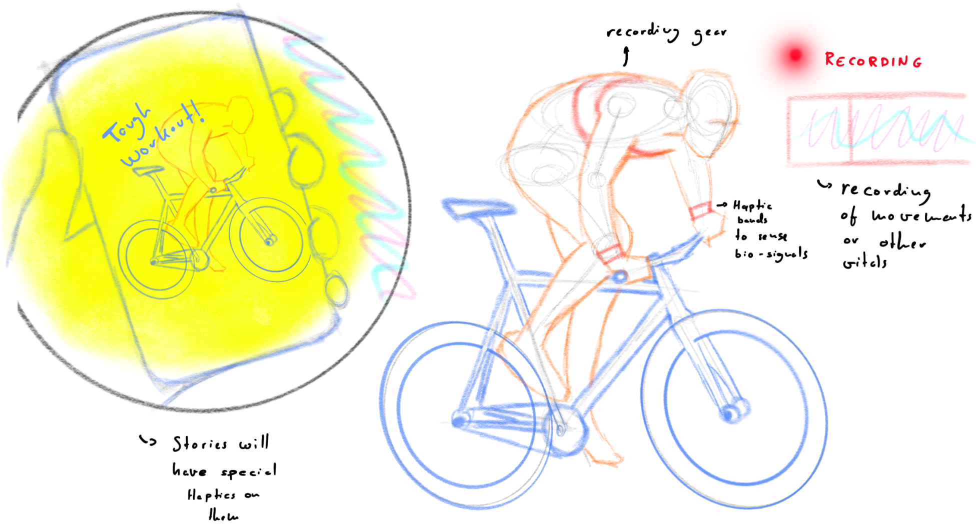


Fig. 79 - Feel stories, encapsulating activities in a format similar to instagram stories

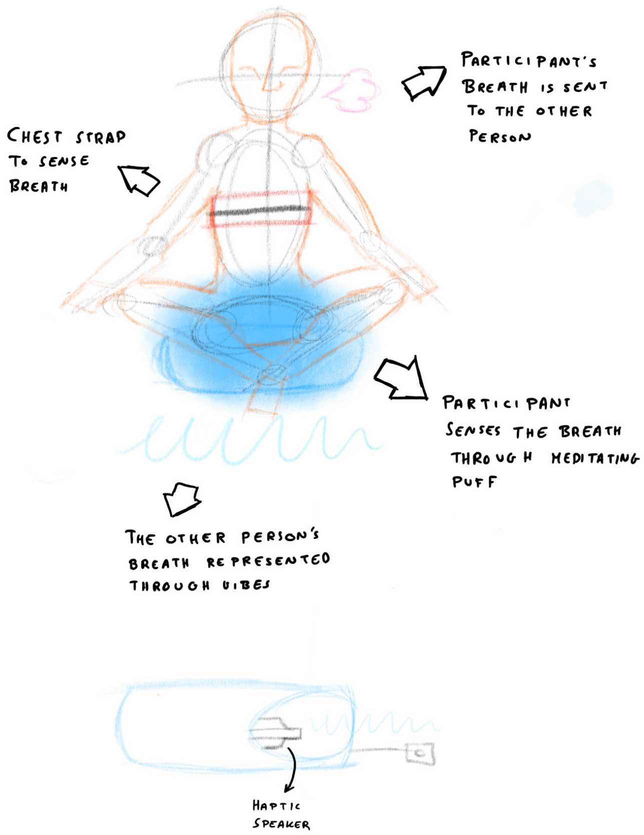


Fig. 80 - Breahting puff 1, to feel the vibrations of another user through meditation puff

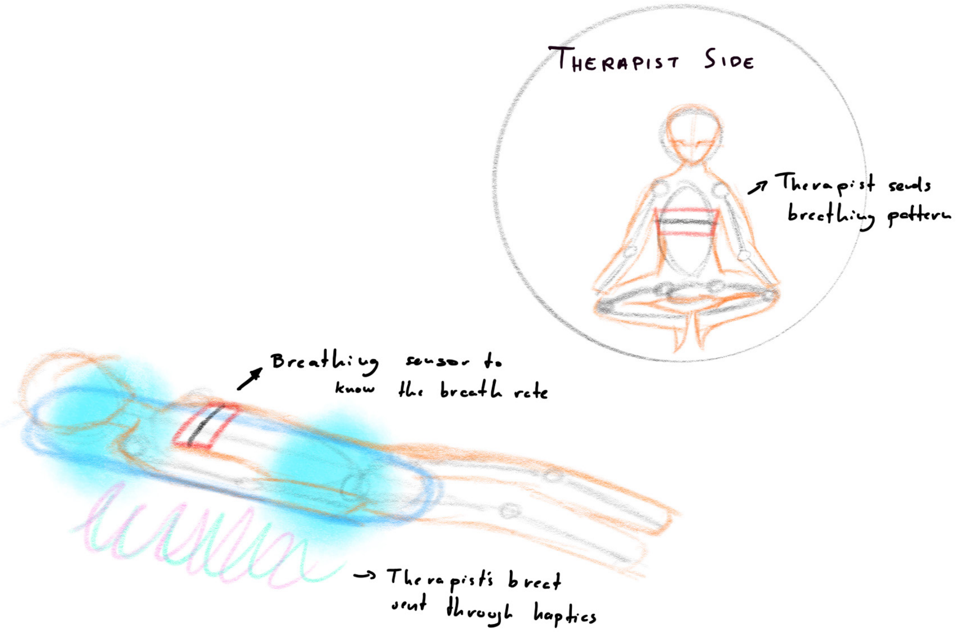


Fig. 81 - Breathing puff 2, to experience whole body vibrations of a guide while laying down

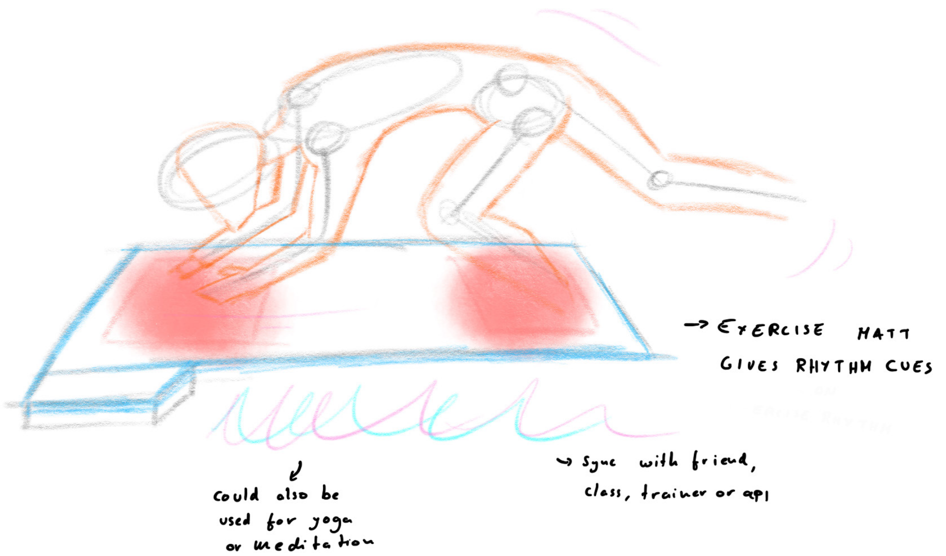


Fig. 82 - Haptic matt, with sensors and motors to synchronise the workouts of participants

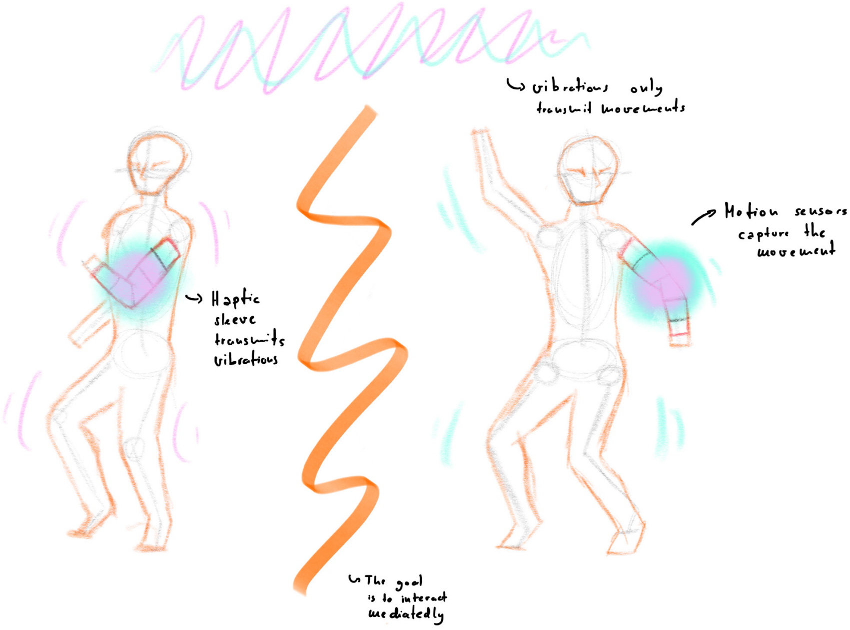


Fig. 83 - Haptic dancing, a sleeve with actuators to create a haptic dancing experience

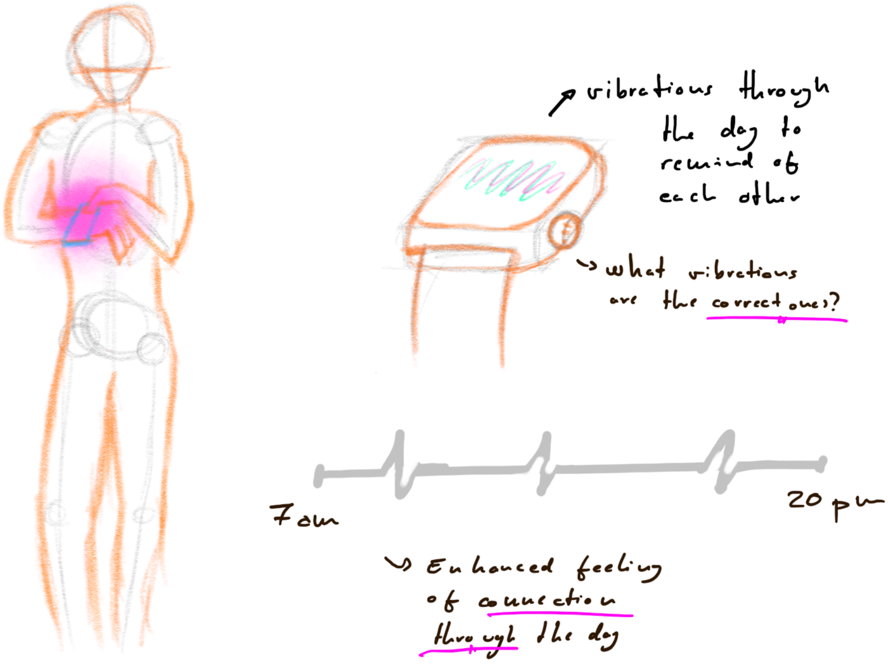


Fig. 84 - HapLink, a device for partners to feel tactons at the same time and connect

Fig. 85 - Meditation bowl, to put on the lap of the participant and feel the breathing of other participant

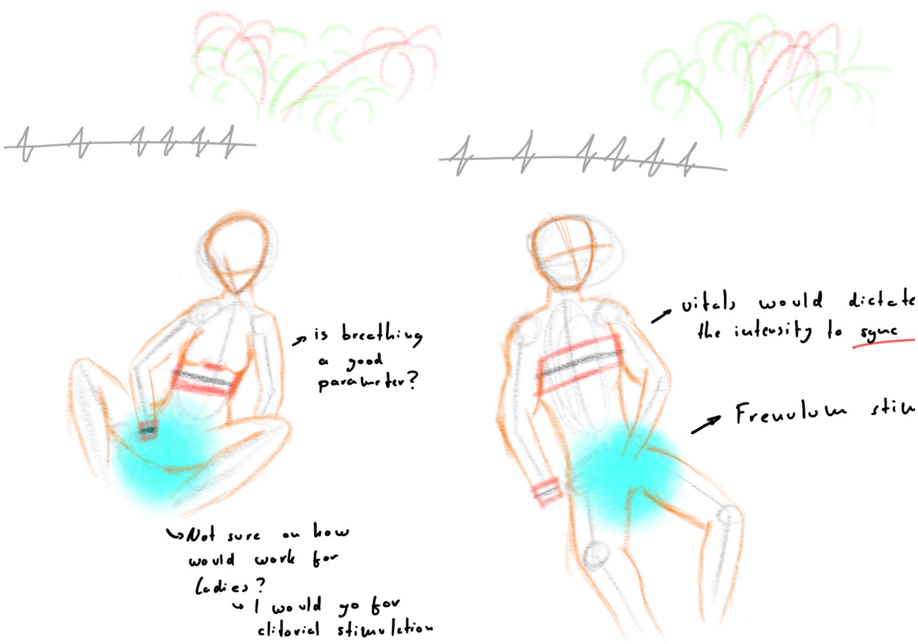


Fig. 86 - SyncGasm, a teledildonics solution to allow partners to orgasm at the same time

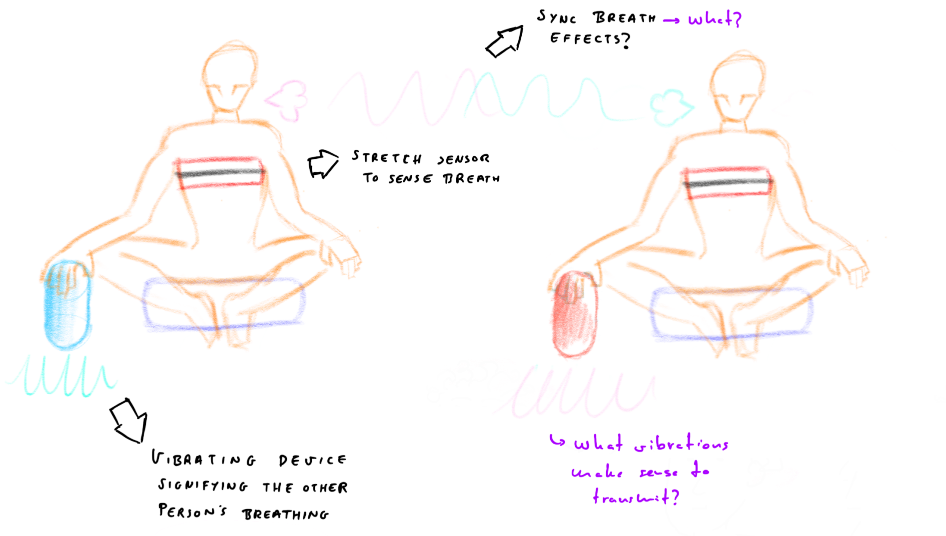


Fig. 87 - A device to feel the breathing of another person in the palm of the hand

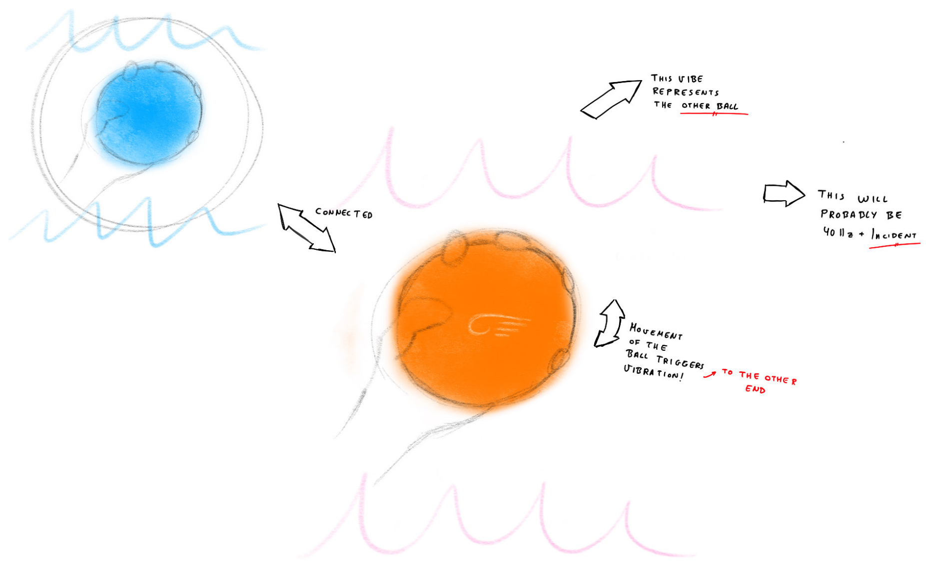


Fig. 88 - PalmLink, a ball-shaped device to syncrhonise the motions of two participants

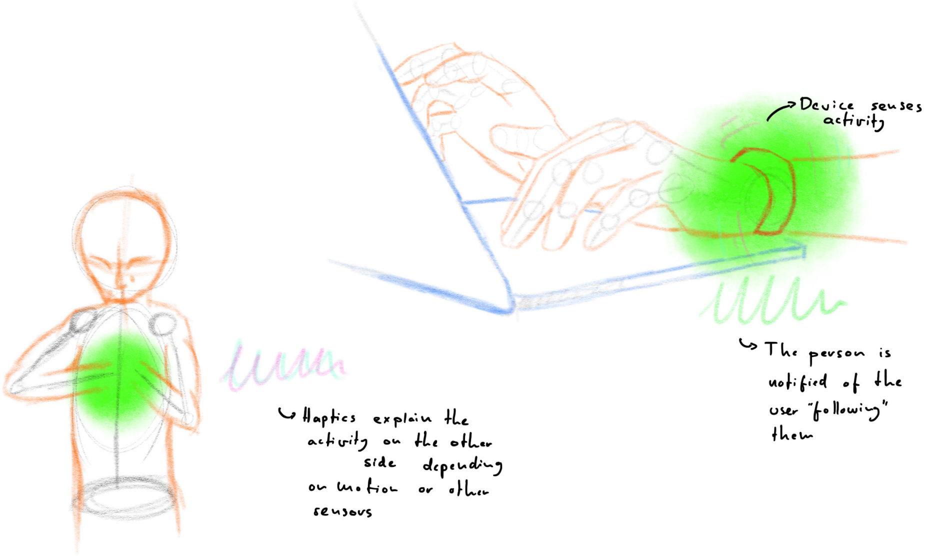


Fig. 89 - The Weasly clock, through capturing movement participants could feel what the other was doing

5. Project Brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Aguirre Uriz
initials: M
given name: Mikel
student number: 5026784
street & no.:
zipcode & city:
country: Netherlands
phone:
email:

Your master programme (only select the options that apply to you):

IDE master(s): IPD / DfI / SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: Honours Programme Master

specialisation / annotation: Medisign / Tech. in Sustainable Design / Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Gijs Huisman — dept. / section: HCD/HICD

** mentor: James Derek Lomas — dept. / section: HCD/DA

2nd mentor:

organisation:

city: — country:

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

Procedural Checks - IDE Master Graduation

TU Delft

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Gijs Huisman date - - signature

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ________ EC

Of which, taking the conditional requirements into account, can be part of the exam programme ________ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name date - - signature

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name date - - signature

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 2 of 7

Initials & Name M Aguirre Uriz Student number 5026784

Title of Project Hapsync: Exploring Non-Symbolic Input for Human Interaction

Hapsync: Exploring Non-Symbolic Input for Human Interaction

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 15 - 02 - 2021 | 24 - 08 - 2021 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

There are a lot of layers to human experience, and when we experience the world, every single one of them adds up to a rich and complex experience. We are able to ride bikes, synchronise while dancing, drive cars and shape clay. And these are only a few actions of the thousands we can experience thanks to our body's capacity to interact with our environments and use it to do things.

Historically however, the computer and digital systems that we have created for ourselves have failed to capture and use all that wide range of abilities that our body can perform through action and experience. They have been focused on graphical interfaces, which do a good job for certain things, like writing this paper, but leave a lot on the table.

In this project, we set ourselves to explore the possibilities of the haptic sense as an alternative to graphic interfaces to support interpersonal interaction. These will be the main topics of interest of the project:

- Capturing & Displaying Non-symbolic information: Current digital devices are not well suited to transmit non-symbolic parts of human experience. Think of dancing, where two people synchronise through touch in an interaction. We will conceptualize ways of capturing and transmitting this information using vibrotactile stimuli and assessing the response of participants to this new type of stimuli.
- Communication: We will be experimenting with the possibilities of haptic displays as an alternative to the ubiquity of graphical interfaces. To do so, we will be conducting experiment rounds using different interfaces and actuators available to us.
- Social behavior and Interaction: Human interaction and experience are very complex processes. There are a lot of levels of communication happening at the same time that we perceived subconsciously and perceptions are changing continuously with the participants'. One of the main challenges of the project will be how to integrate our interventions in this complex environment and how different variables affect perception.
- Prototyping: Given that we are aiming for physical communication, we will need to make prototypes that allow us to test the interactions.

To explore the solution space, we will rely on conceptualization and testing cycles. This approach was defined in Camille Moussette's thesis Simple Haptics as the "best way to learn, understand and seize the full potential of this new modality. Explorative and experiential qualities take precedence over technical accomplishments."(Moussette, 2012).

Limitations:

Given the physical nature of the project and the current restrictions due to COVID-19, some difficulties are expected to appear through the project, like the possibilities of group experiments and limitations on the setting and interaction, for instance. This is also a highly subjective matter of preference, even though some evidence exists on patterns of effects on certain vibrations (Aguirre, 2021).

Stakeholders

The VibeResearch Lab has the aim to investigate the human experience of vibrations and how they can be harnessed for good. Their human-centered approach to topics like psychophysics is a new way of understanding this part of science and integrates it amazingly with design.

space available for images / figures on next page

Personal Project Brief - IDE Master Graduation

introduction (continued): space for images

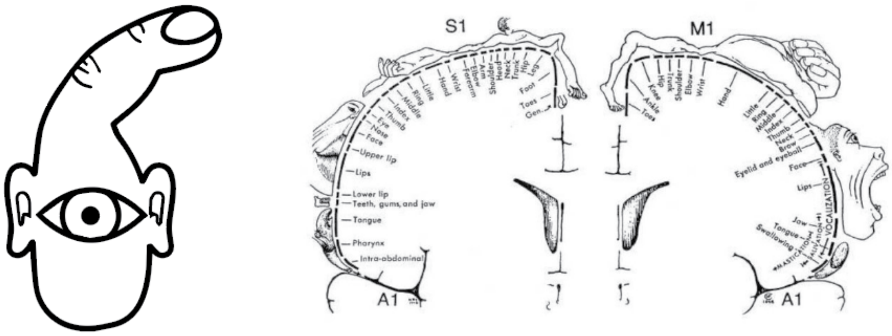


image / figure 1: "how computers see us" (O'sullivan & Igoe) vs the sensory-motor homunculus (Penfield & Boldrey)

image / figure 2: Touch is a crucial sense in our development and daily interaction (R. Ramistella)

Initials & Name M Aguirre Uriz Student number 5026784

Title of Project Hapsync: Exploring Non-Symbolic Input for Human Interaction

TU Delft

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Digital interaction design has been focused on the development of interfaces focused on the visual and, less so, acoustic senses. This means that the nature of the interactions with our technology, and therefore the interactions it mediates between people, are constrained to what this senses can do. Gaver & Strong (1996) explain it in the following quote:
"They (collaborative systems) rely on symbolic messages—usually language—which means that communicative acts must be overtly articulated by the sender, and that their reception is a relatively focused and attention-demanding endeavor for the recipient. The use of symbols also implies that the process is one of transferring information, whether about facts or opinions or beliefs."
This paragraph is still relevant after 25 years, and the proliferation of devices and their visual interfaces is adding up to the point where companies are looking for alternatives, like haptic displays. The haptic sense is a peripheral sense that operates constantly. Not only that, but the nature of touch interactions open a big opportunity to the nature of information we can transmit, and therefore, to the kinds of interactions that can be sustained by haptic technology, specifically tactile vibrations in our case.
We approach the field with an interest in embodied interaction and the possibilities of expanding on the possibilities of capturing and transmitting human experience, through means that allow us to step out of the use of symbols. We set ourselves to explore this space, experimenting with how the perception of different symbolic and non-symbolic information works, what kind of interactions this modality supports best and what interfaces allow all this to happen.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

1) Explore the possibilities that haptic displays for interpersonal interaction with different experiments
2) Develop interfaces that capture different parts of interaction to be transmitted as tactile vibrations
3) Take the learnings on the process and create a framework for future implementations of haptics in interaction design

In the first part of the project, we will be investigating the field with different experiments about human communication through haptic vibrations, using different actuators and tools and iterating depending on what we find of interest in each instance. For each experiment, we will be designing our own interfaces to allow the interaction to happen in what is called "haptic sketching" (Moussette, 2012).

Our approach will rely on conceptualization and evaluation and reflection cycles to find out what concepts align with the outcome we are looking for. The inspiration for this process is Camille Moussette's Simple Haptics and the guidelines he presents for Haptic Interaction Design

The final deliverables of this project will be double. First, we will develop a final version of the interaction that we see more promising, based on the concepts we previously presented. Second, we will present a discussion on the process we followed as a framework for future haptic interaction design projects.

We will record video footage of our sessions, as it is a format for story-telling and critical reflection (McDonnell et al., 2014).

Initials & Name M Aguirre Uriz Student number 5026784

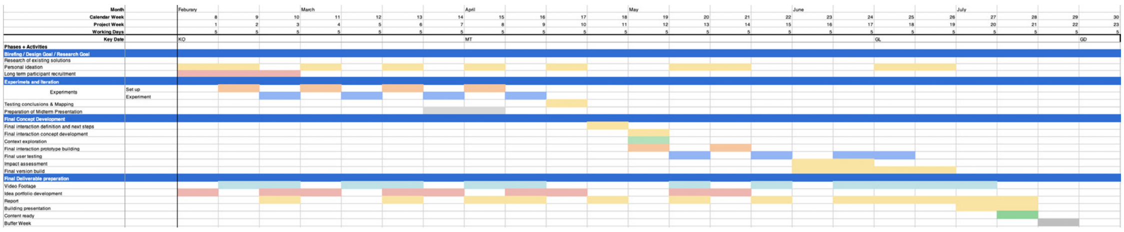
Title of Project Hapsync: Exploring Non-Symbolic Input for Human Interaction

Personal Project Brief - IDE Master Graduation

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 15 - 2 - 2021   24 - 8 - 2021 end date



The project builds strongly in experimentation and iteration, as it will allow us to more effectively explore the design space. We will base our work in previously made research, and we want to dedicate this project to the exploration of the design space, meaning that we will want to start hypothesizing and conceptualizing as soon as possible. This will mean conducting building, testing and iterating so we have a portfolio of concepts and some tests conducted when arriving to the midterm presentation.

From there, we will continue the experimentation process with several test runs. This will allow us to know how people react to different interventions and interactions. We aim to get a solid understanding of the possibilities of the technology both in a conceptual and practical level. We will then select one of the concepts or proposed interaction which seems more interesting and develop it into a final version.

Experiments could include:
- Vibration playgrounds meant for the participants to navigate different spaces with different goals, like transmitting certain sensations to another person or creating vibrations together (playful interactions)
- Pre-composed vibration patterns that participants will use to convey certain meaning or pair with different images or clips (perception and identification of vibrations)
- Testing different hypotheses, like locations for different effects (light nudges, pleasurable sensations, affective touch...)

Finally, we will extract the learnings of the process we have followed and propose it as a framework for future projects in the subject of Haptic Interaction Design.

Personal Project Brief - IDE Master Graduation

TUDelft

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

The TU Delft is an environment full of topics and ongoing projects that you have to explore. In my final project I wanted to do something that mixed the ones I found more interesting. First, Haptics is a field of research that I have recently found and I really have enjoyed working with, as designing for the sense of touch is a very fascinating and unique subject.

Designing for embodied interaction and to support our possibilities to sense and do things is something that caught my attention from the beginning of my trip in haptics, and this is an opportunity to develop that into the next level. During this six months I expect to grow the complexity of what I have done so far and push the field towards a human centered approach of interaction design, through the usage of haptic vibration displays.

Finally, I am also very interested in methodologies like Research through Design (RtD) and experiential prototyping, where design is used to explore non-design related using experiential prototypes. In this case the combination of technology with the possibilities of haptics to convey new kinds of information in a topic like communication, which is a very complex topic, significant for mental well-being and human fulfillment sounds like an amazing brief.

The main learning points of this project are:
- A hands on, human centered approach to haptic design (something already of interest on the field of haptics)
- Designing interfaces to capture and display other things apart from visual and acoustic information
- See how mediated interaction fits within the complex and dynamic patterns of human interaction
- Working on a serial design and experimentation sprint processes

Personal ambitions
- Take my knowledge on haptic interaction design to the next level
- Improve my prototyping skills outside digital visual interfaces
- Make an awesome project that is in pair with some of the crazy projects I've seen, like Affordance ++, Feel the Vibe and others
- Learn more on the realm of haptics, enactivism, communication and perception

References:

- Strong, R., & Gaver, B. (1996). Feather, scent, and shaker: Supporting simple intimacy. In Proceedings of ACM Conference on Computer Supported Cooperative Work (CSCW '96; pp. 29–30). New York: ACM Press.
- Moussette C. (2012), Simple Haptics: Sketching Perspectives for the Design of Haptic Interactions

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.