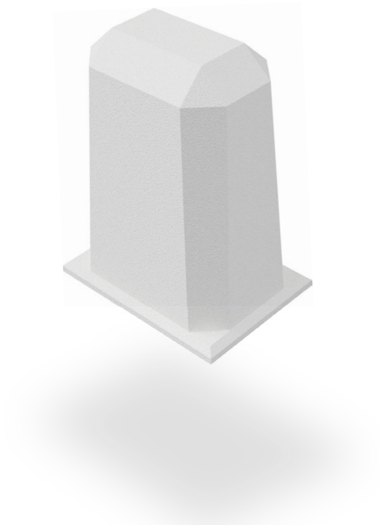

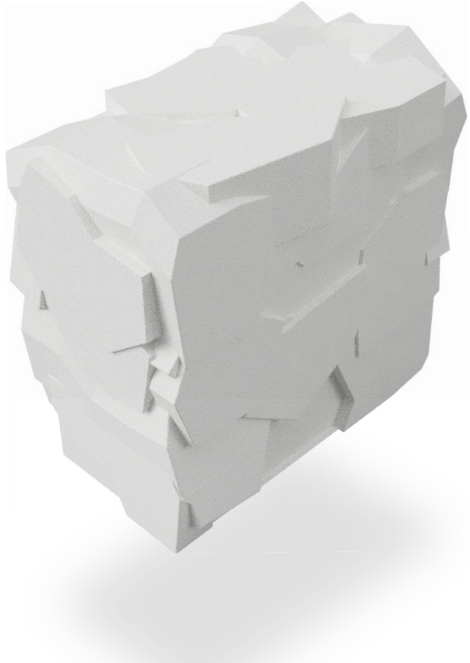

Co-designing vibrations without vision and hearing

Using cross-modal perception to support communication with people with deafblindness

Master Thesis | Design for Interaction | Xavière van Rooyen

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Preface

Dear Reader,

I would like to take a moment to share with you my personal perspective on this project, as it has been an incredibly rewarding and eye-opening experience for me. I often sketch my thoughts in order to create structure (believe me, you do not want to see my illustrator file for this project).

During my graduation project I was positively forced to extend to communicate via a different modality. As I delved deeper into the subject matter and spoke with individuals who heavily rely on haptic senses, I found myself becoming more and more intrigued by their expertise.

I want to thank all the wonderful people who took the time to share their experiences and who opened my eyes to their world of haptic perception. Your stories have touched me, and I am incredibly grateful to have had the opportunity to learn from you. Without your time and effort I would not have been able to complete such a meaningful research.

Also a big thanks to all the other participants who contributed to this study by coming along to co-design sessions, brainstorm sessions and your claymodelling art.

I would also like to thank my supervisors for their support, engagement, and belief in my - initially somewhat vague - ideas. Gijs, for sharing your knowledge of the world of haptics. Myrthe, for sharing your knowledge and experience with the haptic experts and connecting me to your network. Sylvia, thank you for your enthusiasm and your critical view. And to Eric from Bartiméus, thank you for your time, advice and fruitful brainstorm sessions in Doorn.

A special thanks to my friends for your listening ears. Ruby for your encouragement, Celine, Anne, Charlotte and Noa for your on-point jokes during our coffee breaks. A big thanks to my parents (A.K.A. my temporary roommates) for being so supportive in times of last minute stress and celebration. And last but not least, Bo for keeping me grounded. Your support, in countless ways, has made a significant difference.

Xavière

Executive summary

Human-computer interactions should be as inclusive as possible, nowadays. Designers play a vital role in making products, services, and systems usable by a diverse range of users. Mobile applications use vibrations (tactons) to convey information about, for example, messages coming in. The quality of vibrotactile communication can be greatly enhanced by involving in the desing proces the experts when it comes to feeling: people with deafblindness.
By involving the haptic experts, mobile applications using vibrotactile communication can become more inclusive for all users.

This thesis addresses the challenge of usability versus flexibility when co-designing with haptic experts. The goal is to establish an equal level of control among all co-designers, including the haptic experts. To achieve this, Shape2Vibe has been developed by using a research-through-design approach. The design process drew inspiration from cross-modal perception. Moreover, clay modelling experiments were conducted for creating embodiments of four dinstinct basic vibration effects from Adafruit's haptic motor library.

Shape2Vibe has proved effective in facilitating communication during the co-design process, enabling participants to express their ideas through the positioning of blocks. Equal control is ensured for all co-designers because communication for all participants is brought to the same level. The four shapes representing basic vibration effects adequately support co-design sessions for everyday design cases, such as fire alarms.

However, designing vibrations to convey emotions or association-based scenarios requires additional communication and a more layered approach due to the context dependent nature of emotions. Therefore, it is recommended to further research wether more association based shapes facilitate more abstract design cases.

Overall, this thesis contributes to the advancement of inclusive designs by assisting other designers in co-designing vibrations with haptic experts. By having involved haptic experts, the research has succeeded in creating an inclusive and usable tool and method useful for applications in the field of vibrotactile communication.

Table of Contents

* Throughout the current study, people with deafblindness will be mostly referred to as ‘experts’ or ‘haptic experts’

1. Introduction

This chapter introduces the context and relevance, the aim and the approach of this graduation project.

1.1 Inclusive design

For a design or a product to be inclusive, it should be accessibe to and usable by as many people as possible according to the British Standards Institute:

> Inclusive design is "the design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible ... without the need for special adaptation or specialised design." - The British Standards Institute.

These days, human-computer interactions are becoming more and more inclusive. A law adopted by the European Union in 2016 requires public bodies (local and national) to make their websites and applications accessible to as many users as possible (Orwa, 2023). Companies such as Apple and Microsoft are constantly researching to improve the accessiblity of their products. The aim of most companies and governments and/or institutions for that matter, is to reach an increasing number of users. For instance, Apple has tried to improve the accessibility of their products for people with visual impairment by using voice-over in order 'to hear what's happening on your screen' (Apple, z.d.). However, Xiaomi Inc. found that for people who are visually impaired, voice-over is often inconvenient in, for example, noisy surroundings. Not only can the voice-over be disturbing to others, it also does not take privacy into consideration.

Designers play a crucial role in the process of making products, services and systems more inclusive and therefore usable by as many as possible. One of the key challenges designers face is being aware of the potential consequences of their design decisions (Waller et al., 2015). The example of Apple's voice-over feature demonstrates that in real-life situations products may present challenges that are different from what was initially anticipated.

As a solution to any inconvenience of voice-over, Xiaomi Inc. have developed a User Interface (UI) that helps a person with visual impairment 'feel' the UI. When hovering over the screen the phone plays different vibration patterns, resulting in communicating a user interface through vibrotactle patterns (see Figure 1) (iF Design - Haptic - Making the Visually Impaired Feel the UI, z.d.).

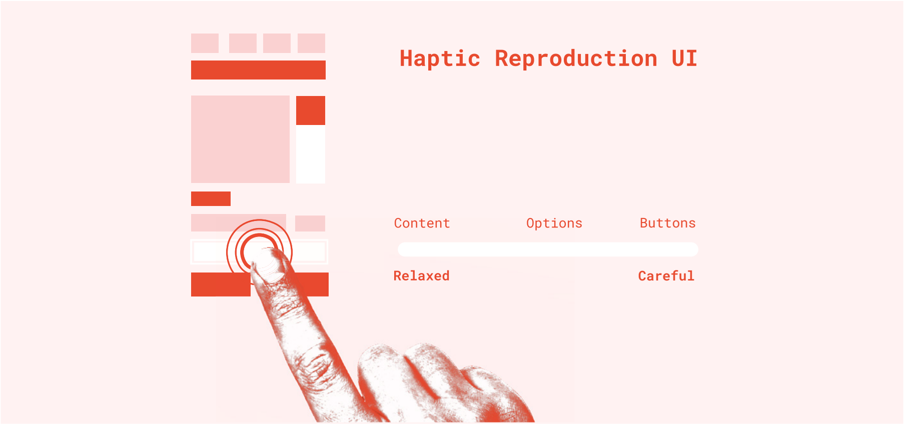


Figure 1: Xiaomi Inc. The vibration communicates the importance of the content on the User Interface

1.2 Vibrotactile communication

Over the years, all kinds of applications have been developed with tactile communication, making use of haptic signals. For example, e-mail notifications have a different vibration pattern from twitter notifications. So, without looking at the mobile device, the user already knows what type of message is coming in (Wittchen et al., 2021).

Vibrotactile communication is currently most commonly used for mobile phones, game controllers, remote controllers (Choi & Kuchenbecker, 2013), and augmented reality (Zhu et al., 2020). In fact, possibilities are endless. The techniques can even be integrated in, for example, gloves for long distance communication (Frederiks et al., 2013).

1.3 Co-designing with experts: People with deafblindness

Knowledge about vibrotactile communication implemented in applications could be greatly enhanced if, during the design process of these applications, the experts of haptics could be involved as experts: People with deafblindness. After all, this group relies on a tactile form of communication on a daily basis. You can think of braille, but also of comprehending surfaces and objects, of communicating and perceiving the world around them. Co-designing with these experts puts everything under a magnifying glass, metaphorically speaking: If vibration patterns are intuïtive for them, it will certainly also work for everyone else and make life easier for all users, and thus making design, in general more inclusive.

For obvious reasons co-designing for and with people with deafblindness is a huge challenge. And what is more, hardly any research involving haptic expterts has been carried out or published, so far. So, designer in general are lacking the (right) tools and method for being able to co-design with haptic experts.

1.4 Project aim

The aim of this project was:

To create a tool and method that, when used in combination, enable designers on the one hand and haptic expert (people with deafblindness) on the other hand, to collaboratively design meaningful vibrations.

Therefore, in this project two main parties were involved, namely designers and haptic experts. Apart from these two parties the project closely collaborated with an institution that focuses on people with deafblindness, namely Bartiméus. Stichting Bartiméus is a Dutch foundation dedicated to providing care to those who are visually impaired or blind. Bartiméus is part of an overarching system, namely DB-connect. DB-connect is a Dutch portal where information regarding deafblindness is gathered from the following organisations: Kentalis, Visio, Kalorama, GGMD and Bartiméus (dbconnect.info, 2023).

Within Bartiméus there is the department Fablab that researches technology trends and solutions that might be worthwhile implementing for people with a cognitive and visual impairment (and sometimes also hearing impairment). Because Bartiméus Fablab has much expertise about the experts as well as about finding technological solutions for them, Bartiméus Fablab has been asked to take on an advisory role in this project, so as to make optimum use of knowledge which is already available. Figure 2 shows the aim and the collaborating stakeholders for this project.
The focus of this project is depicted in the centre of Figure 2: It is all about making a tool and method for co-designing, accessible to and usable by people with deafblindness. So, this project is a means to, and one step before an eventual inclusive design.

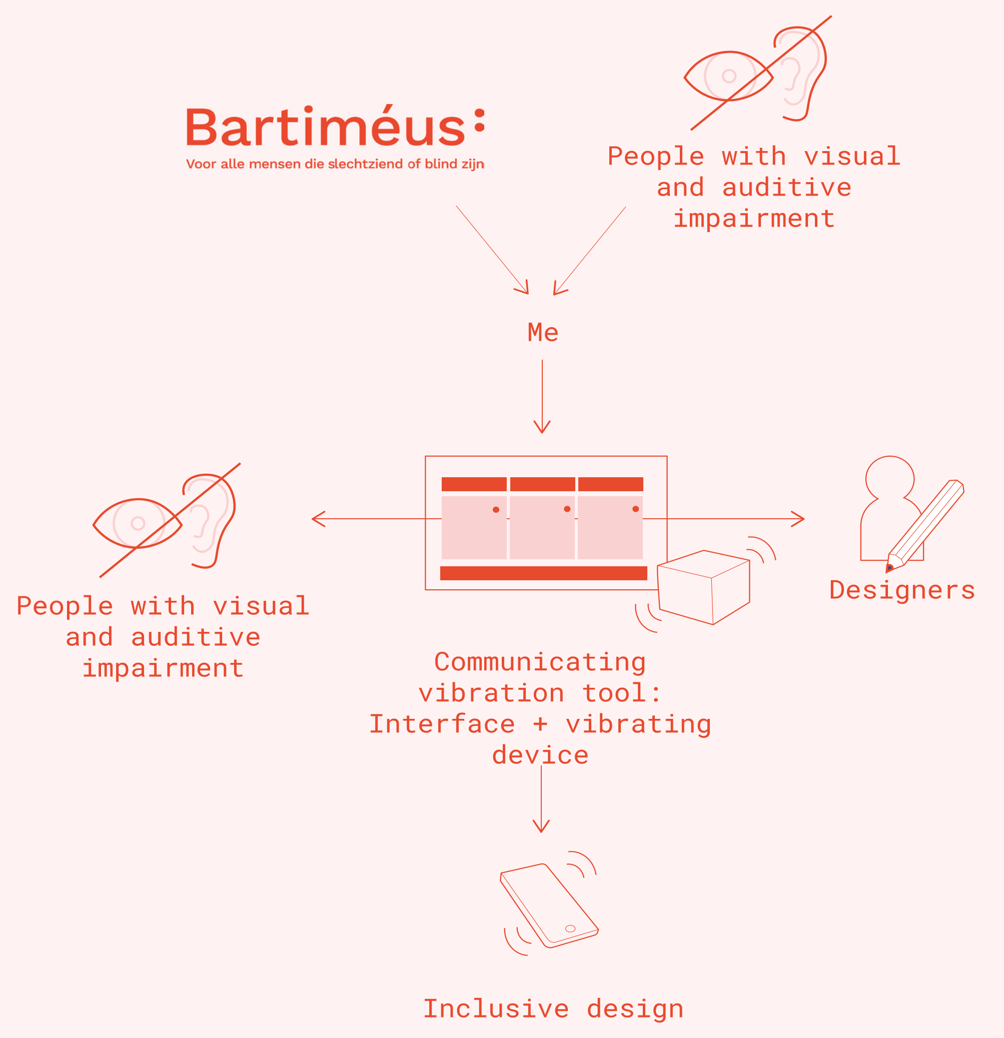
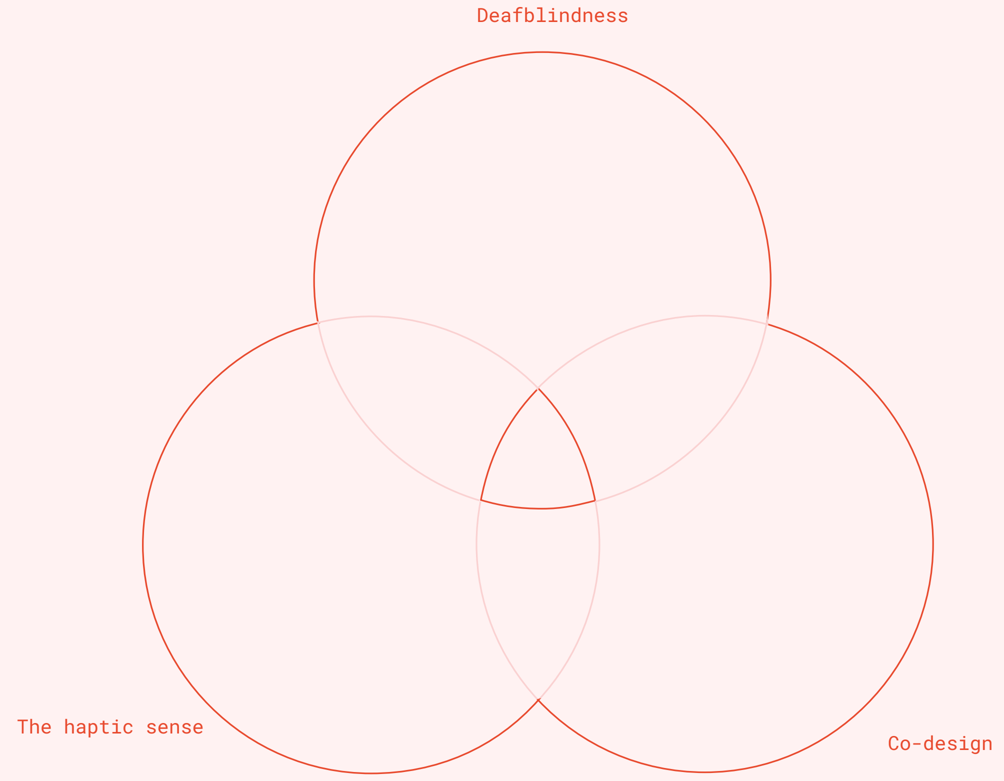
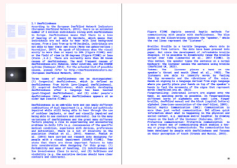


Figure 2: Schematic overview of the project with its stakeholders

2. Background

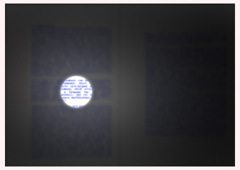
In order to create an understanding of the three most important terms used throughout the rest of this report, this chapter provides background information on: Deafblindness, the haptic sense and tactons, and co-design.





What you see

What someone sees with an acquity of 30%



What someone sees with a field of view <30 degrees.

Figure 3: What does blindness mean?

2.1 Deafblindness

According to the European Deafblind Network Indicators (European Deafblind Network, 2014), there is an estimated number of 3 Million individuals living with deafblindness in Europe. Deafblindness means that, as for the deafness, there is a loss of hearing of at least 35 Decibels. This means that individuals with an auditive impairment are not able to hear with loud noises in the background. From a loss of up to 90 Decibels, individuals are not able to hear their own voice (Mate van gehoorverlies | Hoorwijzer, 2017). As for blindness: We speak of blindness when the visual acuity is more than or equal to 30% and/ or the field of view is 30 degrees (Figure 3) or less (Visio,z.d.). There are currently more than 80 known causes of deafblindness. The most frequently occurring causes of deafblindness are: Rubella, Usher syndrome, and the CHARGE sydrome (Dammeyer,2014). For the extended list of possible causes, the reader is referred to http:// deafblindindicators.eu/ (European Deafblind Network, 2014).

Two types of deafblindness can be distinguished: (1) **congenital deafblindness**, which is defined as deafblindness from birth (pre-lingual deafblindness), (2) **acquired deafblindness,** which entails developing deafblindness after a language has been learned (post-lingual deafblindness) (Dammeyer, 2014).

Deafblindness is an umbrella term and can imply different combinations of dual impairment (e.g. blind and auditively impaired while still being able to hear through the use of cochlear implants, or deaf and visually impaired and being able to see contours and contrasts). Due to the many variations of deafblindness and the great many different factors playing a role in experiencing and encountering problems in daily life (due to, for example, concequences of the specific medical condition, previous experience with devices, as well as preferences and motivation), there is a lot of diversity in the population (Pawluk et al., 2015). However, Pawluk et al. (2015) have carried out reseach into designing for people with a visual impairment.

There are three important factors to take into consideration when designing for this group: (1) Portability and ease of handling, (2) intuitiveness, ‘less is more’, (Kristjansson et al., 2016) and low invasiveness, and (3) bulkiness and visibility (e.g. the assistive devices should have clear contours and contrasts).

A large number of methods has been developed over the years, making communication by and with people with deafblindness possible. Figure 4 depicts six widely used haptic methods for communicating by and with people with deafblindness. The blue lines in the illustrations indicate the ‘speaker’, while the red lines represent the ‘listener’.

Braille: Braille is a tactile language, where dots in patterns form **letters**. The dots have been pressed into paper. Since the development of refreshable braille displays, it is possible to dynamically renew the braille script over time (Leonardis et al., 2017). With this method, the speaker types the sentence on a normal keyboard; the listener senses the sentence using braille (Deafblind UK, 2023).
Tadoma: The listener places a hand on the speaker’s throat and mouth (Reed et al., 1983). The listener is able to identify **words** by feeling the lip movements and the vibrations of the voice.
Hands on signing is a language derived from sign language: You gently place your hands on top of the speaker’s hands to feel the movements of the signs that represent **words** (deafblind.org.uk, 2023).
Fingerspelling: Individual **letters** are signed onto the hand, so spelling of words is possible. In fingerspelling different sorts of alphabets are used: Lorm, Finger braille, deafblind manual and the block (capital letters) alphabet (American-association-of-the-deaf-blind, 2009).
Social Haptic Communication (SHC): Communication is more than just verbal communication. SHC allows quick information about what is happening in the physical and social context, e.g. applause and/or laughter, by drawing **shapes** on the back of the listener (Kalorama, 2017).
Protactile communication: Protactile communication is a more recent way of communicating which enables two-way or group-sharing communication. The communication has been developed by people with deafblindness and focuses on their perception of touch (Granda and Nuccio, 2018).

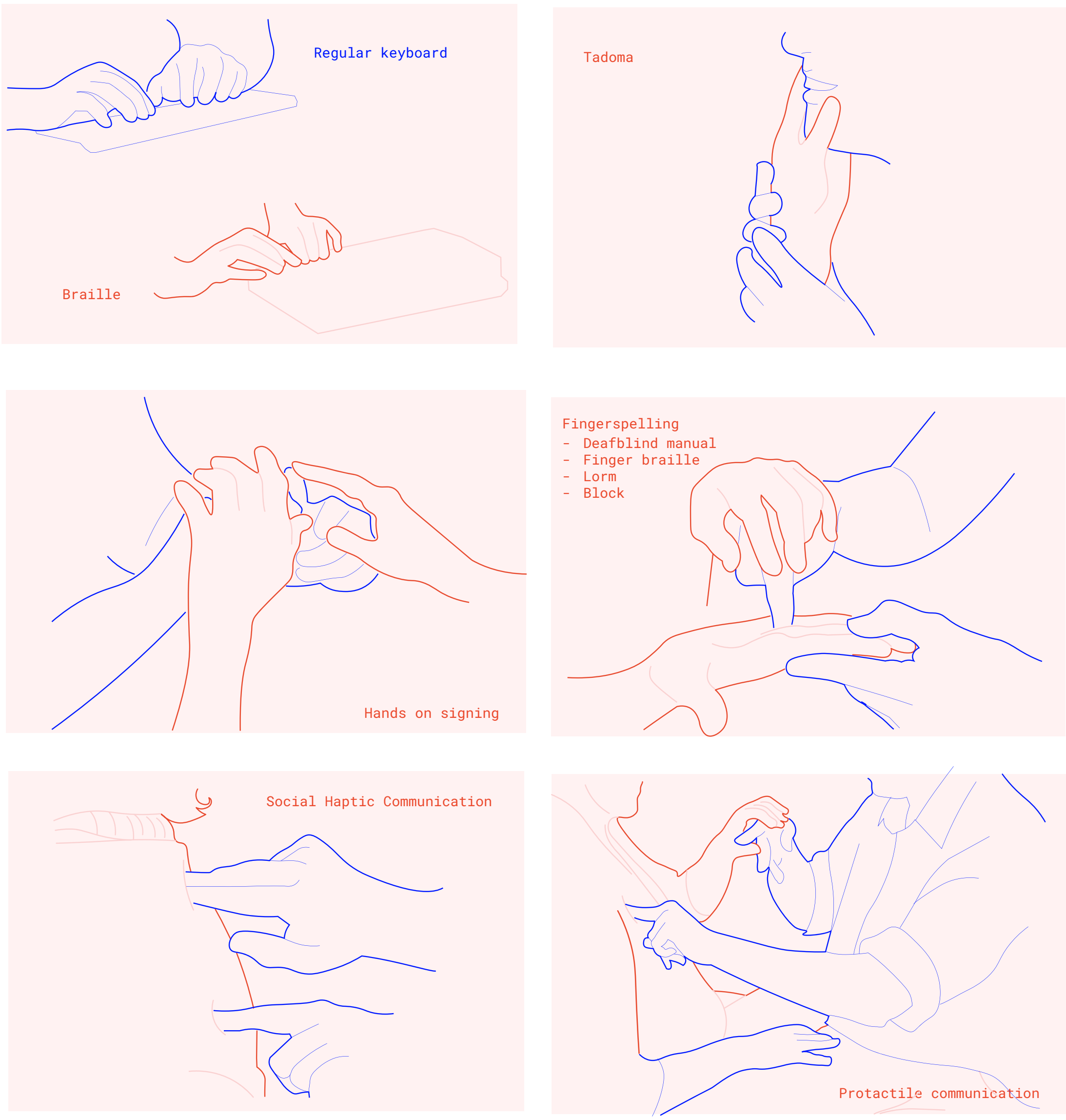


Figure 4: Six widely used haptic communication methods for people with deafblindness

2.2 The haptic sense and tactons

In general, three modalities are active in our perceptual system: (1) Visual, (2) auditory, and (3) haptic. When vision and auditory perception is limited, one has to rely on the third modality, the haptic sense. Haptically, humans are able to explore and perceive object properties through skin contact by touching actively (to touch) or touching passively (to be touched) (Choi & Kuchbecker, 2013). Figure 5 shows six manual procedures for exploring physical properties of objects (Ledermand and Klatzky, 1987).

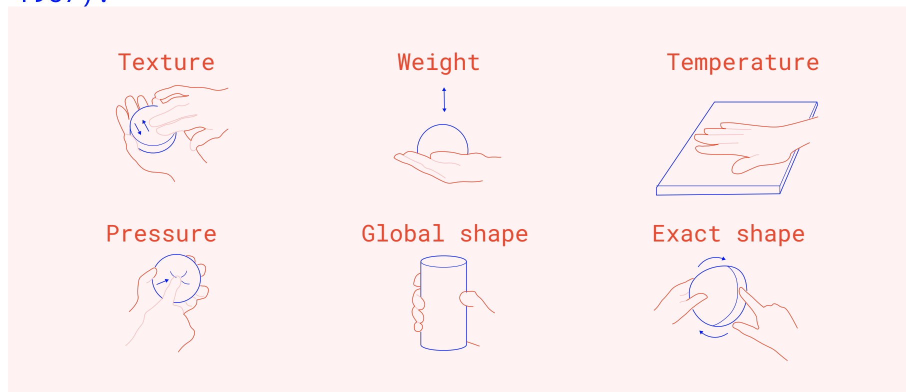


Figure 5: Manual procedures for exploring objects (Ledermand and Klatzky, 1987)

Besides exploring physical properties, humans are also able to feel vibrations. Humans are able to distinguish a vibration's frequency, amplitude, waveform, duration, and location (on the body) (Choi & Kuchenberg, 2013). When variations in these parameters are made, the vibration can represent 'tactons' (tactile icons) (Brewster and Brown, 2004). What are tactons?

> "Tactons are structured, abstract messages that can be used to communicate complex concepts to users non-visually" - Brewster and Brown (2004)

Tactons are designed to be easily memorised, intuitive,and to be able to convey abstract messages, such as emotions. Schneider and McLean (2014) propose a computer program that enables designers to create tactons by adjusting the tactons' parameters. However, this software does not seem suitable for use by people with deafblindness nor for co-design processes, because it uses vision as a way of providing information. Is there a way that tactons can be co-designed for and with people with deafblindness? This is a questions to be investigated in this thesis.

2.3 Co-design

Co-design (collaborative design) is a design method that emphasises the collaboration between the designer on the one hand, and end users and other key stakeholders on the other hand. The method of co-design provides insight into context specific stakeholder experiences and can be deployed at all stages of a design process: From problem finding to eventual evaluation (Vergas et al., 2022) .

For a process to be called co-design, stakeholders and the designer need to be able to collaboratively work on the problem statement. As unpublished research, carried out by Huisman & Plaisier, points out there are two studies that have focused on collaboratively designing tactons. Schneider and McLean (2014) define the following factors needed for enabling a collaborative design process: (1) Asychronous/synchronous feeling, (2) co-located/distributed presence, (3) output mechanism, (4) number of haptic instruments or output devices, and (5) control mechanism.

Schneider and McLean (2014) propose collaborative tacton design including a Graphical User Interface (GUI) on an iPad as control mechanism. This GUI enables one (1) to sketch the different parameters of tactons, and (2) to synchronously feel the designed tactons on two vibrating outputs, in order to create a common understanding of the designed vibration (Figure 6).

Important to note is that GUI's may be hard to interact with by haptic experts. Hardware devices might be a solution to this.

Figure 6: Schneider and Mclean (2014): GUI to sketch tactons and to collaboratively feel output.

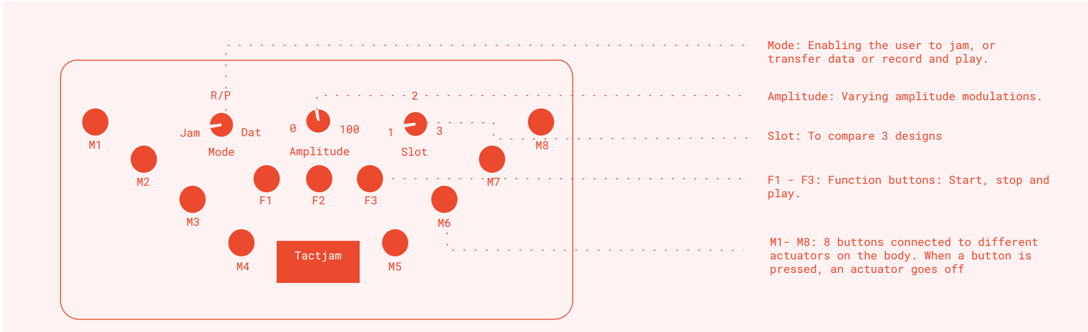


Figure 7: (Wittchen et al., 2022) TactJam; a hardware device for designing tactons

A specific co-design device that examines the co-design process by using a hardware device is TactJam (Wittchen et al., 2022) (Figure 7). Wittchen et al. (2022) stress that such a device should stimulate a fast iterative process for sketching tactons. It should entail at least two abilities, namely:
(1) For sketching: The ability to jam and experiment with the various parameters of tactons.
(2) For recording: The possibility to playback and to reflect on a sketch made.

As mentioned before, hardly any published research is available that focuses on co-design tools specifically for designing with haptic experts.
Theil et al. (2020) describe their co-design process with haptic experts and other stakeholders. They use the co-design method in order to find problems that people with deafblindness encounter in daily life, so in this case the outcome of the co-design is not a tacton. However, Theil et al. (2020) stress the importance of making a given co-design tool also accessible for people with deafblindness, which emphasises the need for the current project.

Plaisier & Kappers (2021) show a method for co-designing tactons collaborating with haptic experts mimicking social haptic communication by using a 3x3 array of vibrating motors on their backs. The researchers showed haptics (by letting vibrations play over the array) representing a social haptic sign. The experts then discussed if they could recognise the sign. It should be noted however, that the experts were not able to design the tactons themselves by means of a co-design tool.

The main objective of the following chapter is to investigate in what way tools can be made accessible for haptic experts specifically for participating in co-designing tactons. But first, in section 2.4, a framework for evaluating accessibility is introduced.

2.4 Three levels of ergonomics

The current project uses the concept of ergonomics as a framework for testing accessibility at different levels.

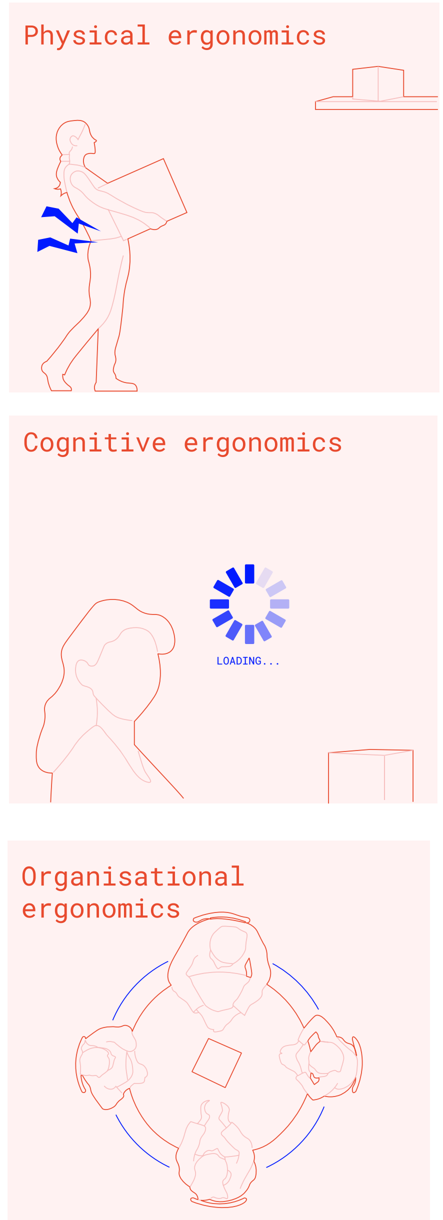
> Ergonomics is the science that focuses on matching tools and conditions to human characteristics that enable people to function optimally. This covers the whole area from, for example, a good office chair to an efficient work process in a restaurant's kitchen.
> - (Ministerie van Sociale Zaken en Werkgelegenheid, 2023).

The International Ergonomics Association (IEA) has identified three levels of ergonomics (IEA, 2000):
- **Physical ergonomics** entails the study of the physical anatomy of humans and focuses on physiology, anthropology and physical activity. In the current study, physical ergonomics includes, amongst others, how heavy it is to use the tool physically. Heaviness refers not only to its literal weight, but also to its reachability.
- **Cognitive ergonomics** concerns the optimisation of interactions between humans and systems such as apps, based on mental processes, perception, and memory. In the current study, cognitive ergnomics involves the way in which people perceive, for example, tactons.
- **Organisational ergonomics** describes organisational structures, policies and processes. In this report the emphasis is on team work and participatory design.

Each of the three levels has influence on the other: If an item is not within physical reach, it might take more cognitive power to reach a goal, making the organisational structure more complicated and vice versa.

Figure 8 shows the three levels of ergonomics and how they are related to this study. The figure also provides questions that arise per level.

Throughout the rest of this project the design criteria and results are presented in relation to the three levels of ergonomics described above, in order to create a consistent understanding of the ergonomics throughout the report on this study.



Is the tool physically tiring to use?
> Can it be handled without using vision or hearing?

Does the tool support a tacton design process?
> What are the mental steps taken in order to design tactons?
> How are tactons perceived?

How well does the tool enable a collaborative process?
> How can you enable collaboration without communicating via vision or hearing?

Figure 8: Three levels of ergonomics

3. Ergonomic studies

This chapter presents three exploratory studies that were conducted to understand how to co-design a tool ergonomically for and with people with deafblindness. The results are presented, separately for each of the three levels of ergonomics.

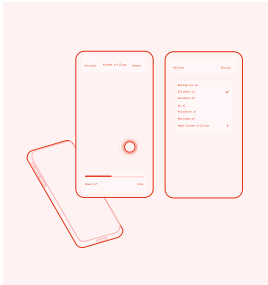


Figure 9: Prototype in Study 1

3.1 Method - Study 1

Participants: Three of the four interviewees had deafblindness; the fourth interviewee had a visual impairment. By using cochlear implants, the participants with deafblindness are able to communicate, so no sign language interpreter was needed. Cochlear implants replace hearing by sending electric impulses to the brain. (kno.nl, 2022). The fourth (hearing) interviewee uses a vibrating device to stay physically balanced. All participants were between 48 and 74 years old, and live in mid- and south of the Netherlands.

The partcipants were recruited via Facebook groups and via the society 'de oogvereniging - ervaringsdeskundigen'. People with deafblindness easily experience distress from travelling from A to B. Therefore, it was decided to conduct the interviews - seperately for each of the interviewees - at their homes, so the interviewees did not have to spend energy on train travels. The researcher of the current project was the (only) interviewer in all four interviews.

Procedure: The interview set-up had been approved by the TU Delft ethical commision. The interview was audio recorded with a laptop app. The audio record was transcribed anonimised. Permission for doing so was given by each of the interviewees via a consent form that was read out to them.

The interviews consisted of three parts that all lasted around 45 minutes. In the first part, the role of (vibro) tactics in daily life was discussed: The participants were asked about the role and meaning of vibrotactile feedback in their daily lives. By way of prototype, an iPhone 10 was used, providing only the possibility to adjust the parameter duration.

In the second part of the interviews, the association of the interviewee with existing vibrating patterns on the phone was observed and examined. The participants were asked to hold the phone while the iPhone's pre-set vibrations were played.

The participants were asked to guess what name Apple had given to the pre-set vibrations and why they thought so. Additionally, they were asked if they had any associations with the patterns.

In the iPhone settings, users are able to 'design' patterns (Figure 9). Users are able to record, save, and play-back a pattern that varies in duration. During the interviews participants were asked: (1) To design patterns for words and emotions (yes, no, maybe, happiness, and angriness) and, (2) to think out loud whilst designing. This constituted the third part of the interviews.

Data analysis: Because the interviews had been transcribed, anonimised statement cards were used, and the data was subsequently categorised according emerging themes (Clarke & Braun, 2016). The statement cards were rated on the following topics: (1) Interactions of vibro(tactics), (2) associations and thought processes in designing, (3) vibration communication, and (4) prototype (phone) interaction.

3.1 Method - Study 2

Participating Organisations: Three out of the four organisations interviewed for this study thesis are part of the overarching system DB-Connect (see section 1.4).
Kalorama is a care institution that provides ambulatory care for people with deafblindness as well as a deafblind centre, where people live permanently or temporarily (kalorama.nl).
GGMD specialises in Mental Health and Social Services for adults, children and young people living with deafness or hearing impairment (ggmd.nl).
Bartiméus see introduction on pg. 11

In addition, **Optelec** was interviewed. Optelec is a manufacturer of assistive devices for people with a visual impairment and also collaborates with people with deafblindness.
The people interviewed were healthcare providers, braille teachers, or teachers of other haptic communication methods. One interviewee has deafblindness and works within an organisation as expert by experience.

Procedure: Through informal interviews over Teams or on the phone, insights about collaboration between several organisations and haptic experts were gathered. The following questions concerning collaboration were asked:
- In what way do you collaborate with haptic experts?
- When does a collaboration work well?
- What can designers learn from your way of collaborating?
- How do you enable a collaboration when they are so dependent on others?

3.1 Method - Study 3

Participants: In the previous chapter, two people were present per session: the haptic expert and the researcher. In this study, three people were involved in the co-design session, namely, the haptic expert, the designer and the researcher. The researcher observed the interaction between the haptic expert and the designer. The designer is an MSc. Design for Interaction recently graduated from the TU Delft. In this study a new case was presented, therefore it was decided to re-contact a haptic expert from among the participants from study 1. Again, like in study 1 the interviews were held at the haptic expert's home.

Procedure: Before visiting the haptic expert, the designer was given the option to define the case study. As in research done by Wittchen et al., 2022, the designer should choose a design goal, context and topic. The case study was defined as follows: "to design unambiguous feedback (design goal) for alerting a haptic expert on approaching people (context), in order to sense social presence (topic)". The designer was subsequently asked to pre-define questions for reaching the final vibration designed by the haptic expert and the designer.
In order to get both the designer and the haptic expert in a creative spirit, a 'haptic memory' game was played.

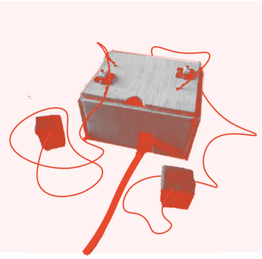
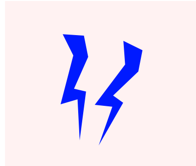


Figure 10: Prototype in Study 3

After having played the game and after being in a creative spirit, an explanation of the prototype was given by the researcher. Both the designer and the haptic expert were given a vibrating output connected to an Arduino UNO board (Figure 10). When either of the buttons was pressed, both vibration motors went off, in order to collectively feel a tacton. In this session, again, it was opted for to make use of a single tacton design parameter, namely duration, in order to keep the prototype as simple as possible. Additionally, this way, the analysis of data could be done in a way similar to the previous study 1 of this section.

After explanation of the prototype, the designer was asked to introduce the case study. From there, the designer took over and the researcher withdrew from the conversation, in order to observe, record and note down the interaction.

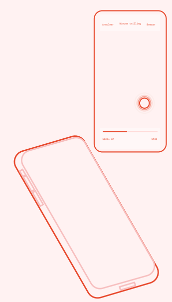
Data analysis: The data analysis was done similar to the one in study 1. The interview set-up had been, again, approved by the TU Delft ethical commission prior to the session. The interview was audio recorded with an iPhone app. The audio record was transcribed anonymised. Via the use of statement cards, the data was categorised in emerging themes (Clarke & Braun, 2016).



3.2 Physical ergonomics: The tool

This section shows the features that a given tool should have for the haptic experts to physically be able to co-design tactons. The results have been based on an analysis of the tool used in study 1 (Figure 9). As stated in section 2.4, the question now is: Can the tool (in this case the iPhone) be handled without using vision or hearing?

The answer is both yes and no. Figure 11 shows, for the prototype used in Study 1, what works well for the expert and what should be taken into further consideration in the final design.

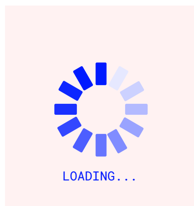


Pros
+ The shape is recognisable
+ Direct feedback
+ User is able to click anywhere on the screen without the need to search for buttons or boundaries

Cons
- Not aware of how long the recording lasts
- The need to adjust intensity
- Users cannot save it themselves: researcher needs to interrupt
- Inability to change designed patterns
- Eventually becomes heavy to hold the phone

Figure 11: Pros and cons of used prototype in Study 1

The findings presented in Figure 11 emphasise the importance of the ‘less is more’ mantra, which entails the use of simple shapes and not much detail. The Graphical User Interface of an iPhone is too complex to be used by haptic experts, which will be further reflected upon in section 3.4.



3.3 Cognitive ergonomics: The design process

The two research questions answered in this section are: (1) ‘What mental steps are taken in order to design tactons?’ and (2) ‘How are tactons perceived?’. The first part in this section focuses on the mental steps, and the second part focuses on the perception the participants had when feeling the tactons.

Figure 12 shows an overview of the tacton design process of the participants that were interviewed. The process can be divided into two phases: (1) The exploring phase and (2) the iterating phase.

In the **exploring** phase, participants first try out the functions of the prototype (step 1). When asked to design a tacton for, for example happiness, participants tend to get stuck, they do not know where to start (step 2). Going back and forth between how the prototype works and where to start (step 1 and step 2), participants arrive at step 3 in which tactons are designed non-intuïtively. Interviewees proposed to design one vibration for the letter ‘A’ and 26 vibrations for the letter ‘Z’. They probably came up with this proposal because it can be related to the way the experts learn Braille or fingerspelling. Admittedly, counting 26 vibrations for one letter is too cumbersome and error prone. Therefore, in order to help the participants to come up with intuïtive vibrotactile patterns, it was decided to give a nudge at this stage. For example, the participants were asked what the word ‘happiness’ made them think of.

The **iterating** phase entails the way in which participants iteratively follow steps 4, 5, and 6 as outlined in Figure 12. At this stage, the participants begin to form ideas in a more associative way. It appeared that their ideas are the result of an iterative process of (1) associations, (2) thinking in extremes (if ‘happiness’ is ‘short’, then ‘angry’ should be ‘long’), and (3) re-feeling their previously designed patterns. It should be pointed out that associations with designed tactons are primarily based on already existing experiences with other vibrating devices, such as the vibration that is felt when the participant is called on the phone or when the emergency alarm goes off. Appendix A shows the extensive list of associations the experts came up with. In addition, it should be noted that the steps in the iterating phase are not followed in a constant sequence. They more or less randomly loop through steps 4-6. After having looped through the iterating steps, the participants arrive at the final vibration solution.

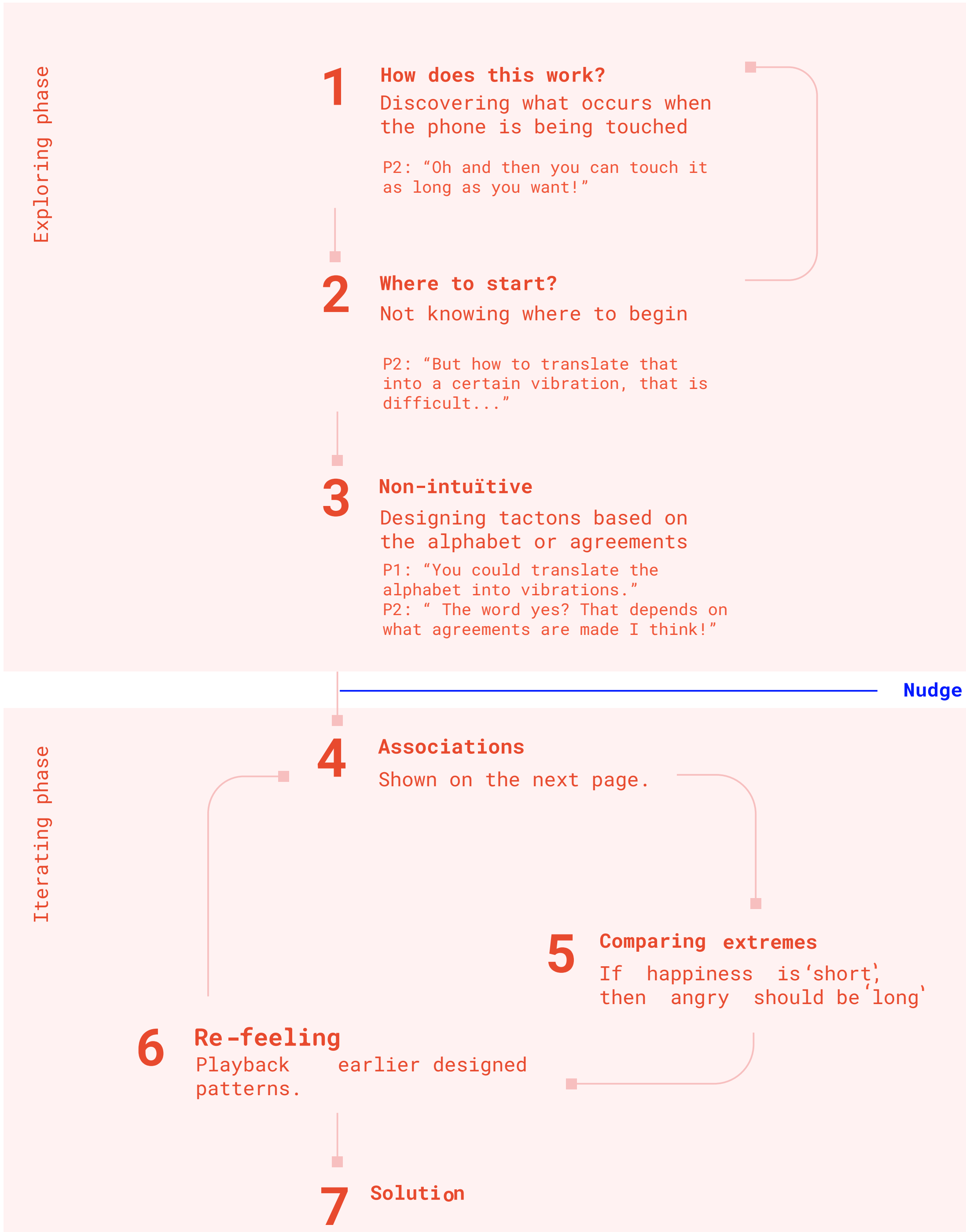


Figure 12: Design process of participants of Study 1. P = participant.

In order to gain a better understanding of how the experts perceive the tactons that were presented in study 1, their communication style describing the tactons was analysed. Six categories of how the haptic expert relates to the tactons could be defined:

Length
P2: “And you notice that it is a very long vibration. Quite long.”
P4: “A slightly longer one and then two short ones.”

Number:
P1: “Two times in a row and then hold.”
P3: “Then I would make it four.”

Time:
P2: “The fire alarm is represented in a vibration of two seconds.”
P4: “I think I would just let it vibrate for a while.”

Weight:
P2: “That is a cheerful and light vibration.”
P2: “But I must say that is a bit heavier than this vibration.”

Emotion:
P1: “I try to pick a vibration pattern which is not irritating.”
P2: “You feel relaxed and at ease during the pattern you just showed me.”

Onomatopeïc:
P3: “Yes, that tut tut tut tuuuuuuuut that tuuuuuuuut.”
P4: “Ehm, tun tun tuuuun, the last one is long.”

As research has shown, vibrations can generally be associated with texture, emotions and can also be visualised (Macdonald et al., 2020, Bensmaia & Hollins, 2003, Seifi et al., 2015). Also Plaisier & Kappers (2021) concluded that the intensity of vibrotactile patterns influences the perception of emotions (e.g. intense tactons were not associated with calm emotions).

3.4 Organisational ergonomics: The collaboration

The organisational ergonomics question that is answered in this section is ‘How can collaboration be enabled without having the ability to communicate via vision or hearing?’.
Figure 13 illustrates how various the organisations that were interviewed (Kalorama, Optelec, Bartiméus, and GGMD) look upon their collaboration with the haptic experts (Study 2, pg. 24). Through the blossom route (going from A to B with a lot of different stop-overs) the haptic experts get to a personalised approach by showcasing options in a market stall, metaphorically speaking.

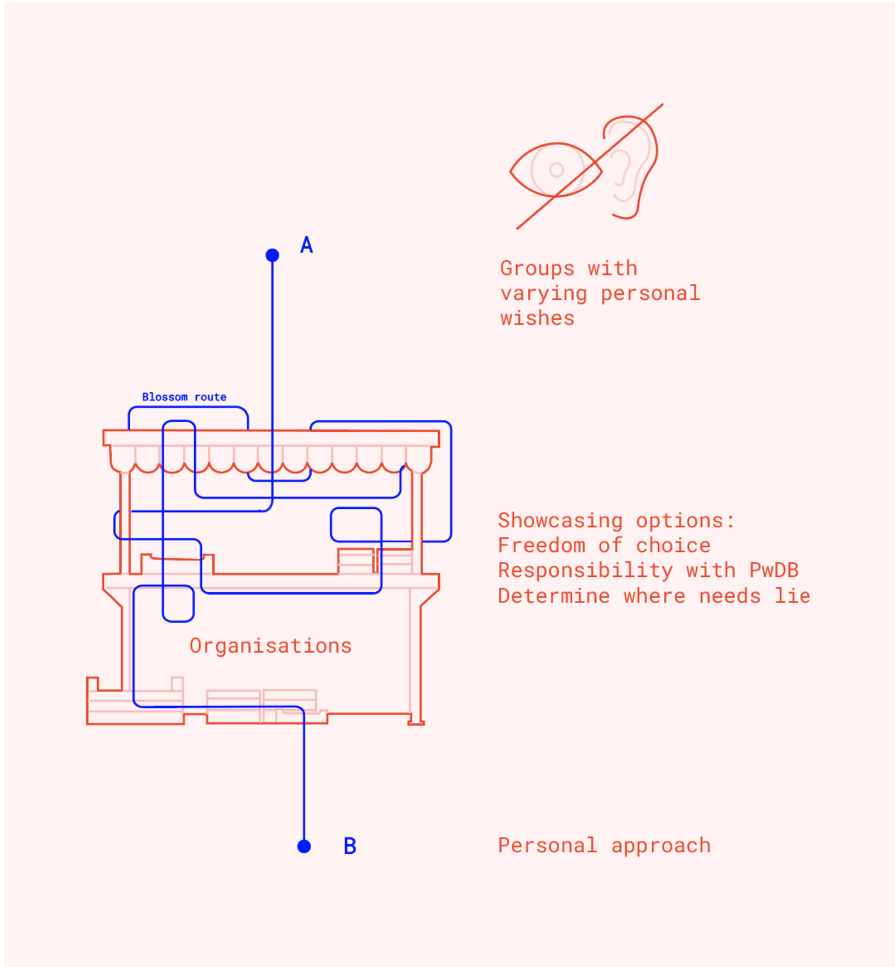
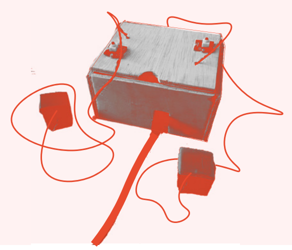


Figure 13: How other organisations view collaboration with experts

Study 3 (for the method, see section 3.1) has provided insight into the interaction in the co-design process between the designer and the expert. The main focus was on how the physical prototype possibly enhanced (or hindered) the collaboration. Figure 14 shows which features enhance (+) and which hinder (-) the collaboration.



Enhance
+ Collaboratively feeling helps the group to create a common understanding of the vibration they are discussing

Hinder
- Having to search for a button breaks the creative flow
- Having to remember previously designed tactons, breaks the creative flow

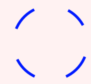
Figure 14: How the prototype enhances or hinders the collaboration process.

Study 3 has also shown the way in which collaboration affects the design process. Because several stakeholders have to agree on a design, it was decided to add two alignment steps to the initial design process, namely: (1) **the design brief alignment** at the very beginning to create a common understanding on the context in which the group is designing, and (2) **the concluding alignment**: deciding to iterate further or to capture the solution. For the final adapted process, see Figure 15.

To summarise, the ergonomics study has provided insight into each of the three levels of ergonomics:

1. The physical tool should be accessible to the experts. Accessibility is achieved through simplicity, intuitivity and recgonisability.

2. Three different stages should be considered during the design process: (1) Exploring, (2) iterating, and (3) concluding.
During the design process, tactons are described in terms of six different properties (see page 30).



3. The collaboration process is enhanced when the experts are first presented with the options, and when they can subsequently haptically explore (market stall principle). To collaborate well, two extra steps must be added to the design process, one at the beginning (step 0) and one at the end of the process (step 6.5). The purpose of these two extra steps is to reach a common understanding between different stakeholders.

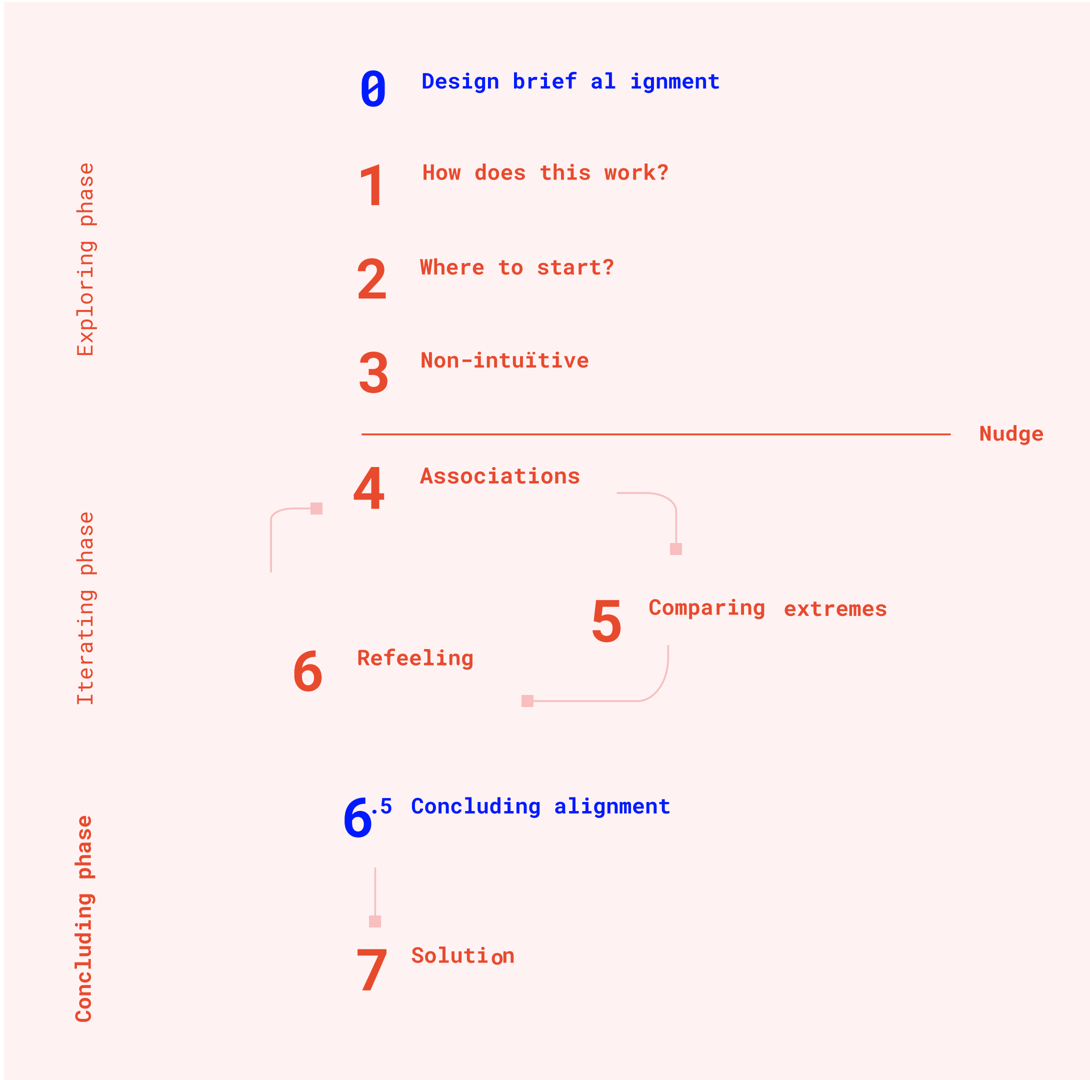


Figure 15: After an observation of a co-design session, two steps have been added

4. Design brief

This chapter explains the links between the different insights gained in the previous chapters. Moreover, the design goal is presented.

4.1 Complexity versus usability

The aim of the current project was to design and develop a tool and method for co-designing tactons being accessible also by people with deafblindness.

Graphical User Interfaces are too complex to be used by people with deafblindness. When something becomes too complex for the experts, a co-design process becomes unbalanced: The individual who does have sight and hearing gains more control, so the process can no longer be called co-design.
Still, there must be some form of complexity for an experience (as defined by a designer) to be enhanced by a tacton. Features such as intensity, being able to compare tactons and playing back are very important in a fluid, and an in-depth tacton design.
Hence, a friction arises between complexity versus usability. The more features the final design has, the more flexibly tactons can be designed. However, with that comes a sacrifice by the fact that as a result, the balance between other co-designers and the experts is not equal.

Figure 16 shows three scenarios with trade-offs between complexity and usability.
Scenario 1. Once the tool becomes too complex, and so it becomes useless for people with deafblindness. This gives the co-designer(s) with hearing and vision too much control which results in them wanting to help the people with deafblindness too much, throwing the co-design process out of balance: A non-co-design process is the result.
Scenario 2. As stated in section 2.1, for people with deafblindness the ‘less is more’ rule applies. But as soon as the tool becomes too simple, an imbalance arises as well, because this does not give enough flexibility for the design team to design in-depth tactons that fit experiences.
Scenario 3. The desired situation is one of co-design, in which there is enough flexibility for designing in-depth tactons fitting experiences and which is, at the same time, not too complex to use.

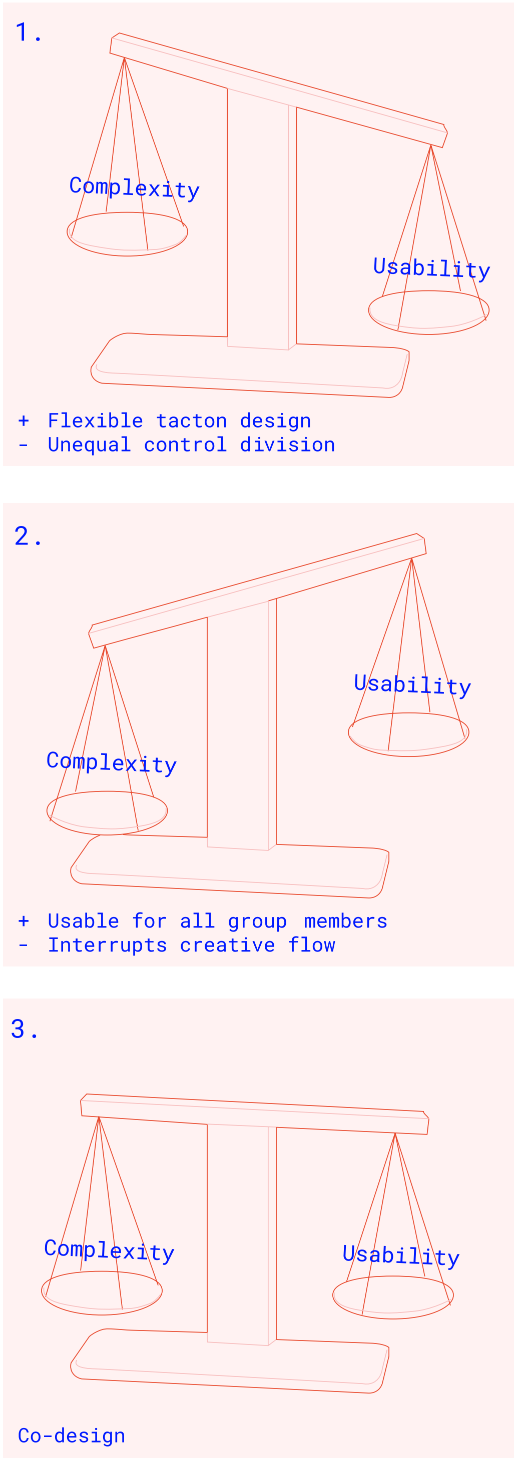


Figure 16: Three situations of trade offs between complexity vs. usability. Scenario 3 is the desired scenario.

4.2 Design goal

On the basis of the literature study in Chapter 2 and the three exploratory studies presented in Chapter 3, the following design goal has been formulated:

Haptic experts and other co-designers[1] should sense an **equal division of control**[2] while **flexibly co-designing**[3] **tactons**[4] that **enhance experiences intuitively**[5] (as defined by a designer) through the use of **haptic perception**[6] for supporting communication.

1 Haptic experts and other co-designers: The co-design group should consist of at least one expert and one designer. The number of haptic experts or designers may vary. In addition, other stakeholders may be involved as well, such as a researcher and/or a professional working with people with deafblindness.

2 Equal division of control: The final design should be usable by haptic experts without the help of others. Because this could lead to an unbalanced co-design (section 4.1).
To clarify: People are always dependent on groupmembers in a collaboration situation. However, it should be possible to use the tool independently.

3 Flexibly co-designing: It must be possible to be able to design without restrictions. As stated on page 32 flexibly designing involves: Adjusting duration and amplitude, making a recording, and re-playing.

4 Tactons: The final design should enable co-designing almost all of the parameters constituting a tacton (mentioned section in 2.2, namely frequency, amplitude, waveform, duration, and location). As for location, only wrist, hands and pocket have been taken into consideration in the curren project (so no other locations on the body). The reason for this is that this study has focused on vibrotactile feedback in mobile devices: A mobile phone can also be connected to a smart watch.

5 Enhance experiences intuitively: The (final design of the) tool should help the co-design group to design tactons that enhance experiences intuitively. The final tool should not focus on morse-code-design (see Figure 15).

6 Haptic perception: To be able to create an equal division of control, the same communication level should be employed by all participants as means of support.

5. Conceptualisation

This chapter introduces the method of conceptualisation and the testing of the various prototypes.

5.1 Principles for intuïtivity

By definition, tactons support an experience in an intuitive way (see section 2.2). Intuitiveness tends to maken complex matters simple. So, in this project basic principles for intuitive design have been defined by means of a brainstorming session held with fellow students of the researcher. Questions such as 'How to perform an action intuitively?', 'What should a design have in order for it to be intuitive?', were the entry points for the session. The principles are the starting point for the design in this project.

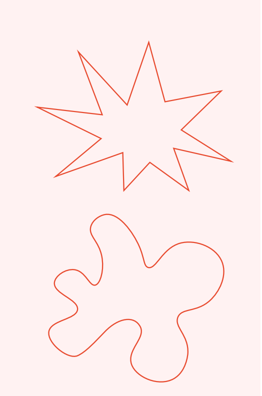


Figure 17: Which shape is Bouba and which shape is Kiki?

An analysis of the brainstorm has resulted in the following three principles for intuitive design:
1) The design should respond to **primary reactions**: There should be as little cognitive effort as possible to use the tool. Essentially, the design should be responsive to the user's initial reactions, making it easy to navigate and understand its functionalities.
2) The design should **remove any hinder** to the willingness to participate: This principle emphasises the importance of removing any obstacles or barriers that might hinder a user's desire or motivation to engage in the design process.
3) The design should be **inviting to use**: This principle emphasises the importance of making the design (haptically) appealing. But also to create an environment that enhances user engagement, for instance by creating a playful experience.

> "The ability to understand something instinctively, without the need for conscious reasoning."
> - Definition of intuition by Oxford English Dictionary ("Intuition", 2023)

At this point I would like to conduct a mental experiment with you, the reader. The shapes in Figure 17 can be classified as a 'Bouba' shape or a 'Kiki' shape. I would like to ask you to go by your intuition: Which would you call Bouba and which Kiki? The answer can be found in the next section.

5.2 Inspiration: Cross-modal perception

You probably think the round shape is a Bouba and the pointed one a Kiki. This concept has been extensively investigated and discussed over the years, and Ćwiek et al. (2022) recently confirmed the most important findings. Most people associate Bouba with the rounder shape, and Kiki with the spiky shape. This is because of the phenomenon of cross-modal perception. Cross-modal perception is perception that involves interaction between two or more different sensory modalities.

The world is full of examples of cross-modal perception. One example to be highlighted, though the comparison is not completely valid, is a scene from Disney's movie Ratatouille (Ratatouille, 2007). The reason why this is not valid is because Remy experiences synthestesia which is not experienced by everyone, Figure 18 shows a still of this scene. Remy (the main character) associates flavours with shapes and music. So, by combining flavours, he can create a symphony.

Figure 18: Remy in Disney's Ratatouille experiencing flavours

Back to the co-design of tactons for haptic experts, now. The question that arises is: Is it possible to connect or associate shapes with vibrations? Can an association with a vibration have properties such as texture, weight, shape and material? And so: Can different 'flavours' (vibrations) be used to create a tacton symphony (rhythms)?
The next section describes to what extent - similar to Remy's flavour experience in Ratatouille - cross-modal associations can be made between vibrations and properties such as texture, weight, and shape.

5.3 Shaping

Visualising vibrations

In the previous section the question has arisen: Can a vibration be associated with properties such as texture, weight, shape, and material? The answer is yes, as already investigated in section 3.3 and by Macdonald et al., 2020, Bensmaia & Hollins, 2003, and Seifi et al., 2015.

Seifi et al. (2015) have developed a website, 'Vibviz', making it possible for users to organise, visualise and navigate in vibration patterns.120 vibration patterns have been categorised as rough/smooth and unpleasant/pleasant. Additionally, labels referring to certain metaphors have been added. Examples of such metaphors are alarm, tapping, musical instruments,drums, and celebration. The envelope of the audio recording of the vibrations has been used as the shape for the visualisation of the vibrations. Seven reoccuring shapes could be defined.

Figure 19 depicts the process of the way in which four clearly distinct basic shapes could be created to be used in the rest of this research. First the seven reoccuring 2D shapes from Vibviz were transformed into seven 3D shapes, so as to make them tangible. To actually feel these seven vibrations, Adafruit's haptic motor library was used (Adafruit DRV2605 Haptic Controller Breakout - Arduino Code, 2014). The library consists of 117 vibrations effects. The effects were analysed on the basis of intensity and duration. And the vibrations that had the best fit with the seven shapes from Vibviz were selected on the basis of duration and intensity. Finally four effects were selected that were most distinct from each other. The way in which these four dinstinct shapes have been determined is answered in the next paragraphs.

Can everyone link the seven basic shapes from Vibviz to these four distinct basic effects if presented in combinations of three, four or five basic shapes? What shapes do people associate with the vibrations? To answer this question, an informal association experiment was conducted, using combinations of different effects from the library. This is done so as to create rhythms of vibrations. Rhythms are important because they create meaningful tactons.

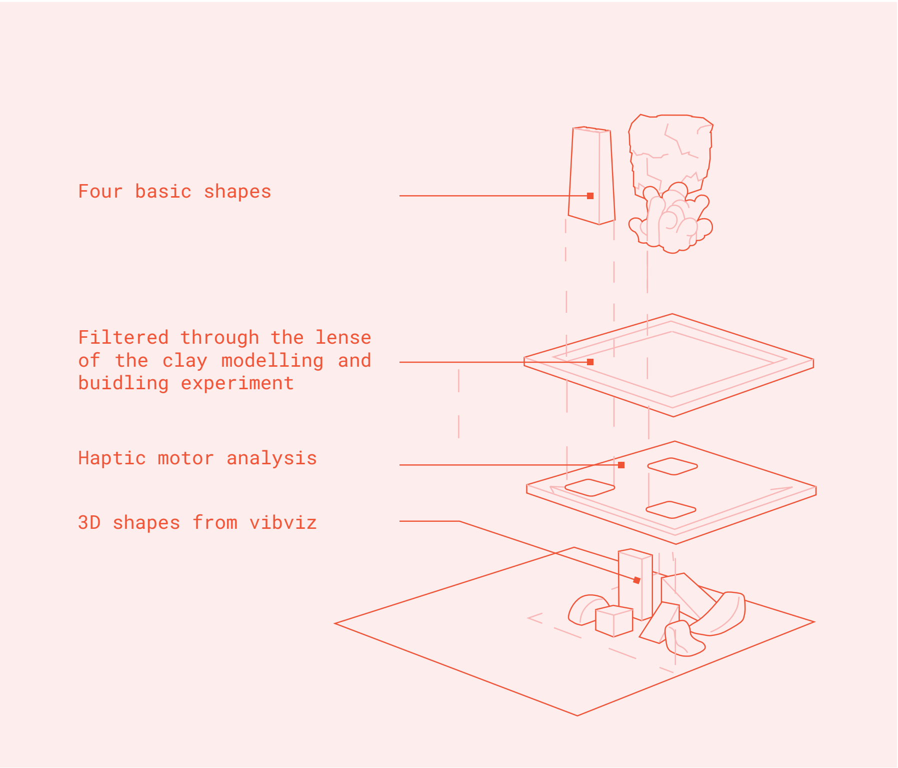
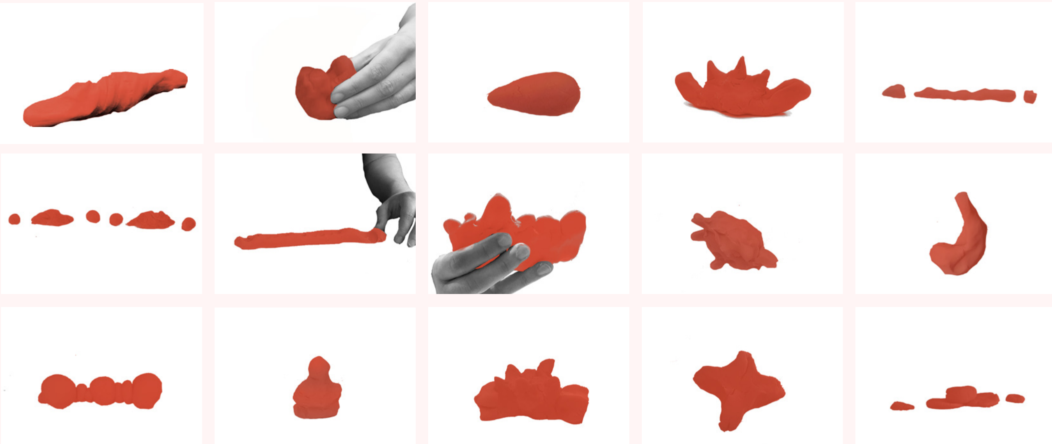


Figure 19: The process of arriving at four basic shapes representing vibrations

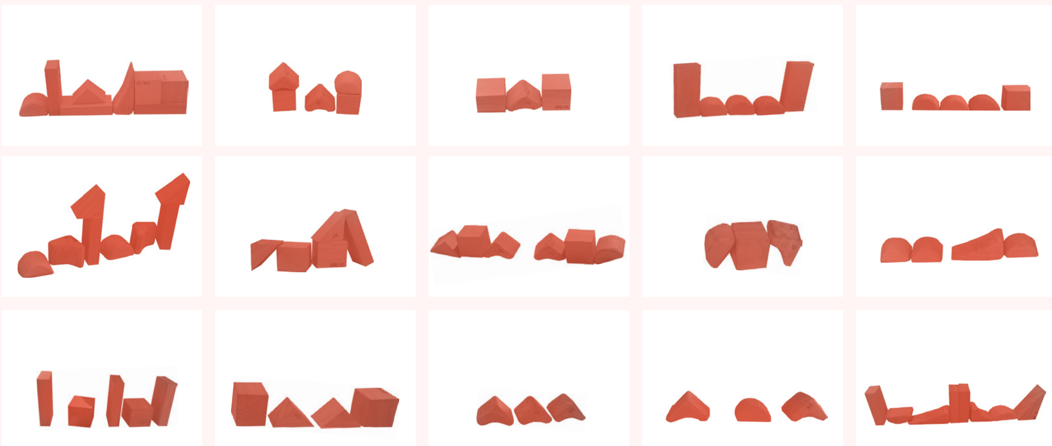
For this association experiment 15 sighted and hearing people participated. They were presented with three combinations of effects. After each combination had been presented they had to sculpt a clay model that according to them reflected the combination of effects or rhythms. This clearly gave insight into the associations they had with the rhythms. Subsequently, the participants were asked to re-create the rhythms with seven given building blocks. These building blocks are the seven basic 3D shapes derived from Vibviz. Eventually, the participants were asked to draw one or more building blocks if according to them any shapes were missing in the set of presented building blocks. The following pages show the participants' results, seperately for each of the three combinations.

Claymodelling and building blocks experiment

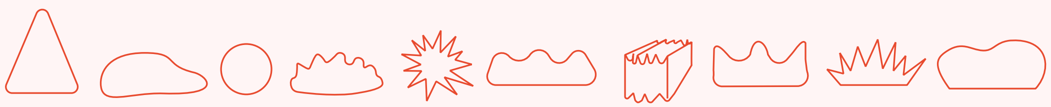
Rhythm 1 : Strong click - Fuzzy 60% - strong click (2 times)
Clay models



Building blocks

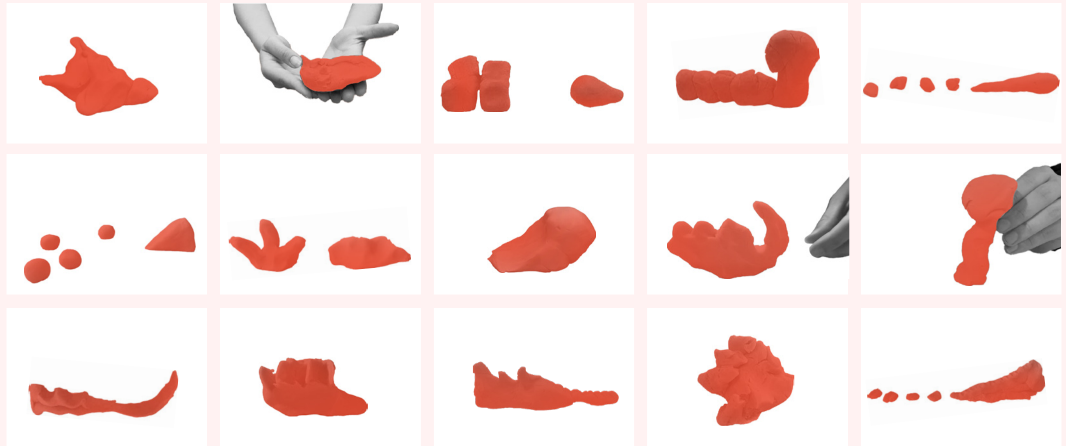


Missing shapes

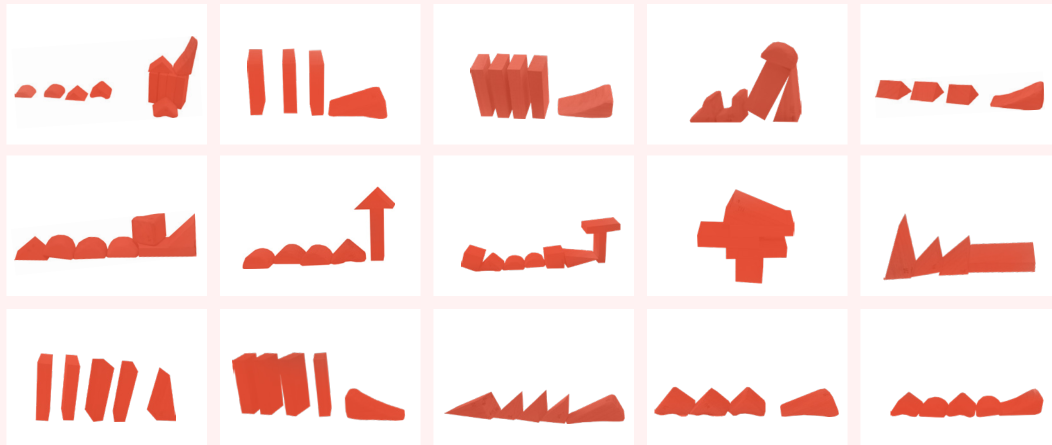


Claymodelling and building blocks experiment (continued)

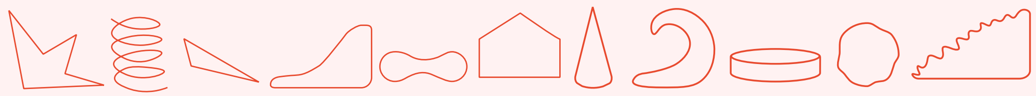
Rhythm 2 Strong click- strong click - strong click - strong click - ramp up long
Clay models



Building blocks

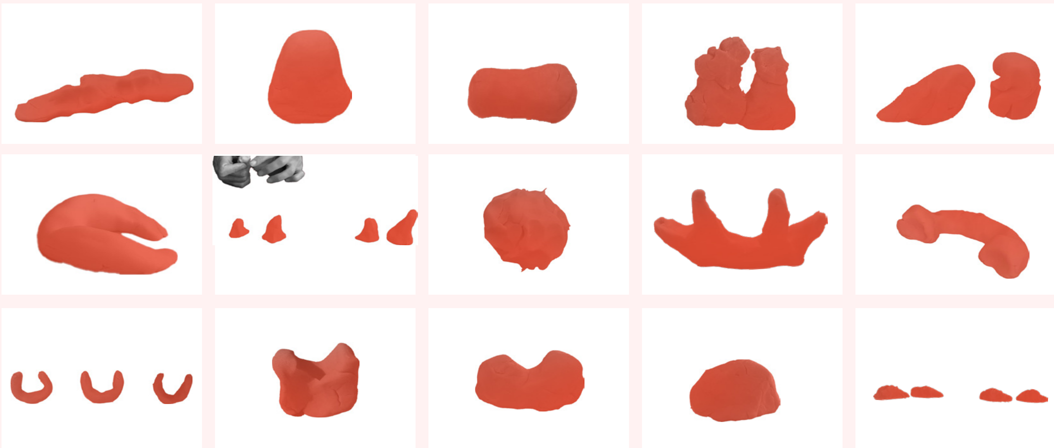


Missing shapes

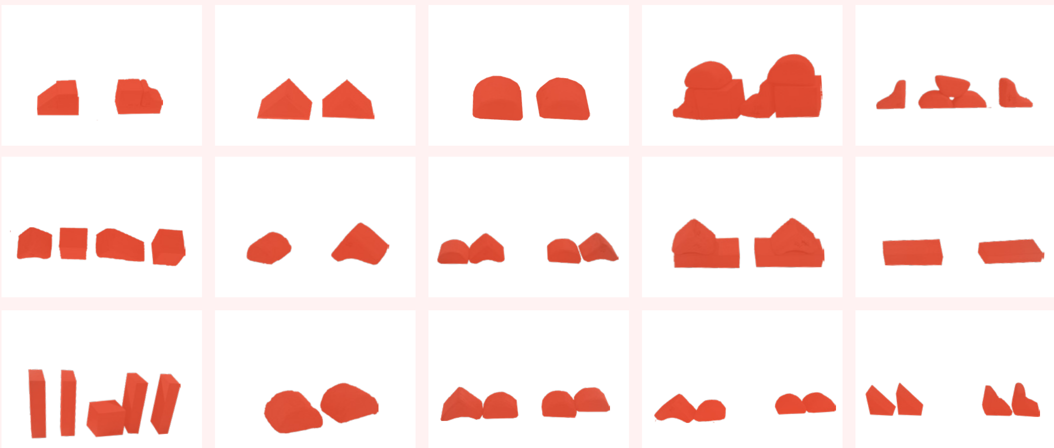


Claymodelling and building blocks experiment (continued)

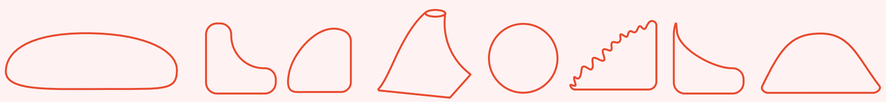
Rhythm 3 Ramp up short - ramp down short (2 times)
Clay models



Building blocks



Missing shapes



The combination of the basic shapes derived from Vibviz, the analysis of the haptic motor library (see Appendix B), and the outcomes of the association experiment has resulted in the four shapes for the tactons shown in Figure 20. The numbers of the effects correspond to the numbers in Figure 20.

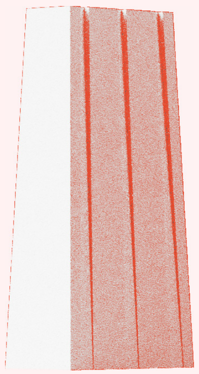
The short click (high intensity, short duration, effect #1) was perceived as edgy and rough. This shape stays close to the VibViz 3D shape. People perceived the short click as a suddenly appearing effect.

A high intensity, and a long duration (Alert, effect #16) was perceived as intense, rough and heavy. The basic shape for this effect.

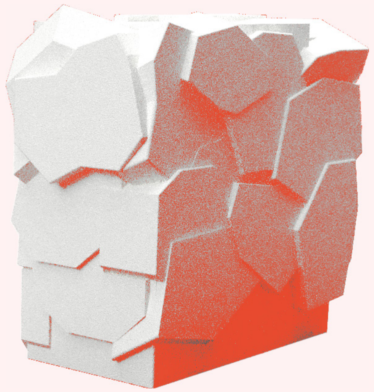
A low intensity and a short duration (fuzzy 60%, effect #13) felt more randomly and ‘flubby’. The basic shape of effect fuzzy 60% represents this random and ‘flubby’ character.

The shape often chosen for ramp-up (effect #82/ #70) was a slowly ascending triangle. Participants however perceived the effect as gradually rising step by step.

Visualisation discussed
The 3D shapes from Vibviz are too restricted in general to be used as visual representations of the vibrations. Participants requested more ‘chaos’ and more freedom when building with the blocks. The freedom of the claymodelling gave more insight into how the shapes match with the vibrations. The combination of the straightforwardness of the 3D shapes on the one hand, and the freedom of the claymodelling on the other, was made. This has resulted in the following building blocks to be used in the final test of the design.

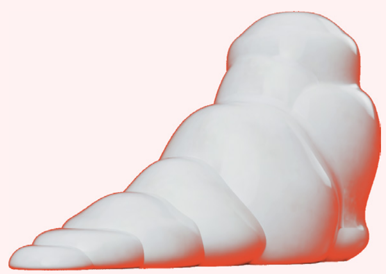


Short click
Effect #1 in library
- 100%
- 250 ms
- Rough
- Edgy
- Medium heavy



Alert
Effect #16 in library
- 100%
- 1000 ms
- Rough
- Edgy
- Heavy

Fuzzy 60%
Effect #13 in library
- 60% (low intensity)
- 500 ms
- Smooth
- Round
- Silicone



Ramp-up/ ramp-down
Effect #82 / #70 in library
- 0-100% / 100-0%
- 1000 ms
- Smooth
- Round

Figure 20: The four resulting shapes derived from an amalgamation of Vibviz, the haptic motor library, and the informal association experiment

During the clay modelling and building experiment, people either (1) directly associated a given vibration with the literal translation of intensity and duration (just like the seven basic shapes and the haptic motor library), or (2) associated a given vibration at a higher level, which was also done by Vibviz by means of the emotional and metaphorical tags in the database. For example, one participant modelled a flower during claying because he felt the ramp-up of the vibration felt like a blooming flower.

It was decided to stay close to the direct translations of vibrations because finding a universal form of high-level association varies greatly from person to person. This would have required more research effort involving amongst others more participants in this experiment. This would not have fit within the limited time scope of this graduation project. Moreover, higher level of associations would, perhaps unnecessarily, have complicated matters for the haptic experts.

It should be explicitly noted that - due to the limited time frame of this thesis - this experiment was informally carried out. No instructions were given as to how the participants should clay model the vibrations (close to the vibrations or rather more association based). So, the results have only been used as an inspiration source for developing the shapes. More structured research needs to be done in order to be able to systematically conclude whether shapes conform to certain effects.

Despite these considerations for future work, the four basic shapes as defined in Figure 20 were useful in the remainder of this project.

How do these four basic shapes work within a co-designing group including a haptic expert? Does it encourage conversation, and, more importantly, how should the shapes be interacted with to encourage collaboration? These are the questions answered in the interaction experiments that are described in the following section.

5.4 Interaction

It is said that people with deafblindness prefer the principle of taking turns when playing games (Theil et al., 2022). The alleged reason for this is that it gives them greater control over the game. Does the preference of taking turns also apply to a situation of co-designing with experts? Or does the turn taking throw the collaboration out of balance?

Three interaction tests were carried out in order to determine the preferred mode of interaction during a co-design process with a haptic expert. So, three co-design sessions were set up, carried out, and closely observed: Two of them were on the TU Delft campus, involving three designers each. The third test - which, because of the fact that the expert could not travel alone, took place at the expert's home - was a co-design session involving one designer and one haptic expert.

The prototype

Figure 21 shows the prototype that was used during the interaction tests, as well as the set-up of the tests. In this case the prototype consisted of:

1. Three to nine copies (depending on how many would fit in the playfield) of each of the previously designed and realised four distinct shapes (section 5.3).

2. The playfield on which the shapes should be placed. Because the shapes are white, the playfield has been made black. This is to ensure that if the expert has residual vision, it is still possible to see the contrast.

3. A play button enabling the rhythm of the combination of the shapes to be played.

4. Three vibration motors/outputs: One for each of the co-design participants. The vibration output should be held in one of their hands. When a shape/block was placed on the playfield or when the play button was pressed, all vibration motors would go off, enabling the participants to sychronously feel what was happening on the playfield. Figure 22 depicts the situations in which the vibration motor would be activated.

5. The prototype has not been fully automatised due to the project's limited time scope. Therefore, the researcher controlled which vibration was played at any given moment via an Arduino interface. For the rest, the researcher was only observing and giving instructions during the process.

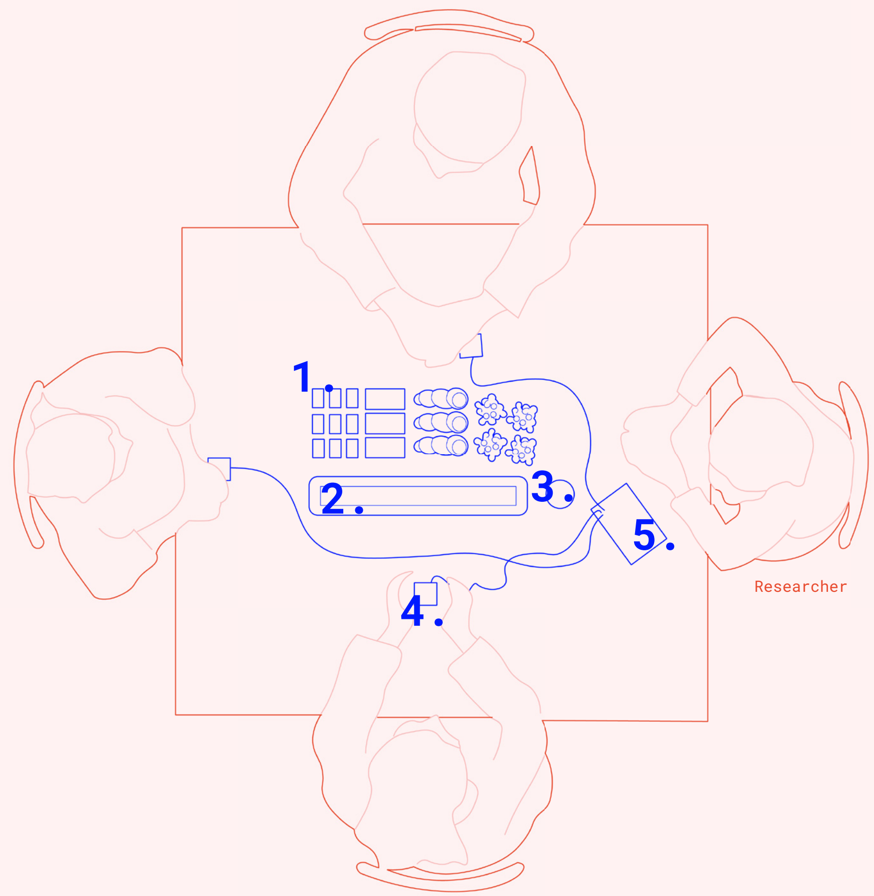


Figure 21: Interaction test set-up

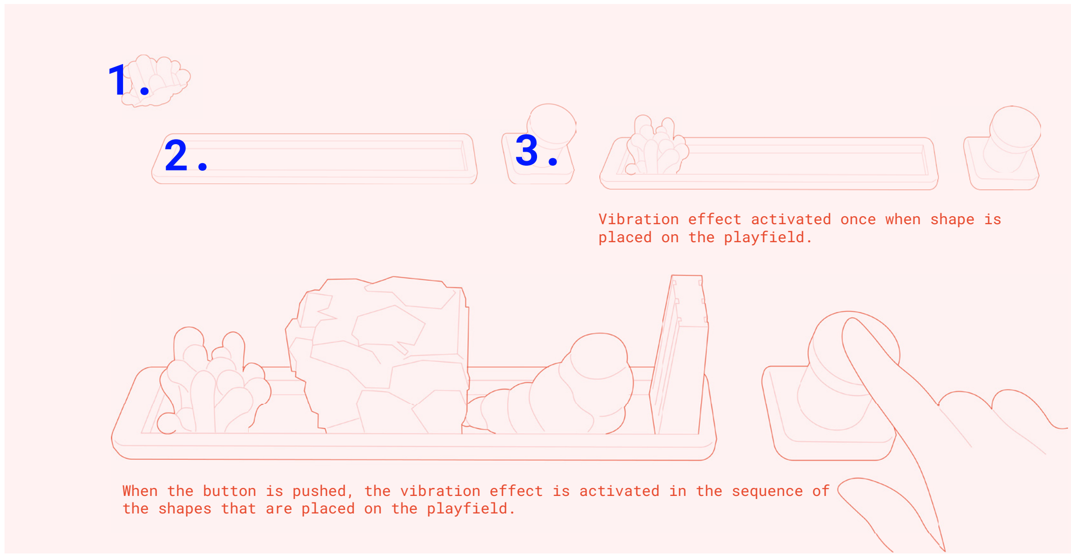


Figure 22: Interaction flow of shapes and playfield

The experimental set up

During the first part of each interaction session, the participants were instructed to get familiar with the prototype and shapes by exploring the various options. This step was and is considered crucial in order for the participants to form a reference frame of the vibrations as represented by each of the four different shapes. To illustrate: A vibration can only feel 'heavy' if one is able to compare it with a 'lighter' vibration. Whilst getting familiar, participants were asked to play a kind of memory game specially designed for this test.

During the second part of each interaction session, participants were asked to perform two design cases: The first case was introduced without any instruction, except for the fact that it was communicated that the final vibration was supposed to represent happiness. The instructions of the second case were that angriness should be designed and to take turns. 'Taking turns' was further explained as follows: One participant starts with an idea and 'builds' it with the shapes. Subsequently - when the first participant has finished the proposal - the next participant goes on building further on the result of the previous participant.

After each of the two cases, the participants were asked to individually rate each of the following statements on a scale of 1-5 (1 is totally disagree and 5 is totally agree):

Q1: I felt I was in control.

Q2: I felt I was equal to my fellow co-designer(s).

Q3: I felt a collaborative connection by using the prototype.

Q4: I felt enough freedom to design.

Q5: I felt that the shapes were supporting my thoughts when designing.

Q6: The prototype was inviting to use.

After both cases, the group was asked which case was nicer to design for: To design without any instruction, or to design with the instruction to take turns.

Results

Figure 23 shows the average answers (n=8) to the six questions. Appendix C shows the ratings of these questions per participant as well as the average ratings. The case where no instructions were given (case 1) was obviously preferred by the participants. In both cases the participants were asked to design a vibration for an emotion and in both cases all participant did not substantially experience the blocks to give them freedom. Section 7.2 goes deeper into why this is the case.

What is also striking to see, is that all participants agree on the fact that the prototype is very inviting to use.

During the interaction test it became clear that the designers wanted more flexibility while the expert thought the design was complex enough.

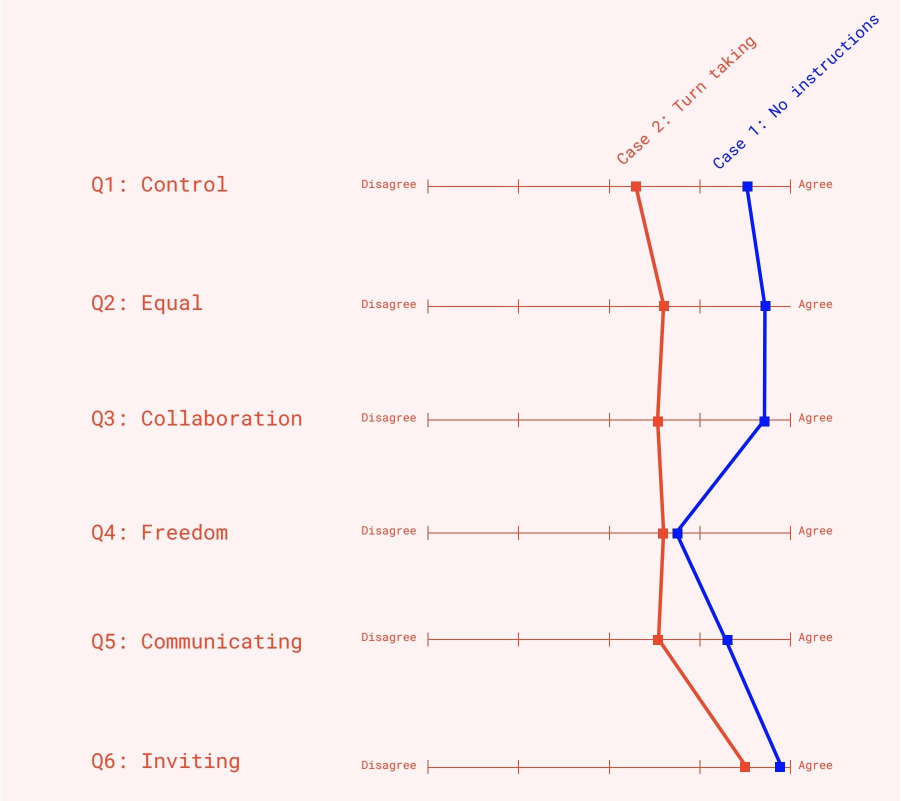
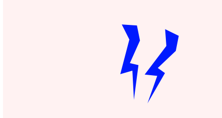


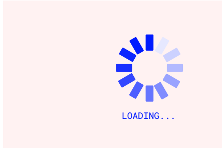
Figure 23: Answers to the six questions after each case (averages n=8)

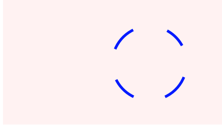
To illustrate a conversation and to what extent the blocks are used as support for communication between expert and designer, part of the transcript of the third interaction test is shown in Figure 24. What is striking in this conversation is that both the designer and the expert are struggling to get started. By putting shapes on the play field, they get ideas of what the final design could be.

HE: That's not happiness either... Hmm I find it difficult.
D: Yes I find it difficult too.... But we can put two of those in a row?
HE: Yes that's a good one!
R: Okay so if you press the button now....
[Rhythm plays]
HE: Yes.
R: Is the vibration complete now or would you like to add a few more?
D: Maybe I would like it to have some kind of ending
HE: Yes and what were you thinking of? This one?
D: Yes maybe!
[Vibration]
HE: No.
D: No that's right. Maybe this one? I'll put it for a moment. Wait then I'll let it play.
HE: Yeah.
[Rhythm plays]
D: Maybe some more of the last one.
HE: Two I think.
D: Okay, let's play it again
[Rhythm plays]
HE: Yes
E and D: YES!
D: So we all agree on that!

Figure 24: Illustrative design conversation between haptic expert (E), designer (D), and researcher (R)







The test results were evaluated on the three levels of ergonomics again: The physical level, the cognitive level, and the organisational level.

On the physical level it can be concluded that:
- The playfield should not be moved. Co-designers should not move the tool around, because otherwise the haptic expert loses control and has to find out, again, where the playfield is. So, the various parts of the tool should remain in place as much as possible.
- The 'short click' (vibration #1 see Figure 20) is not easily firmly positioned. As a consequence, the haptic expert cannot efficiently place the shapes on the playfield.
- The vibration motor should not be held in the hand, so it is of importance that the wires are long enough to go in the pocket. Holding the motor in one hand, the haptic expert was not able to explore the prototype well, because both hands were occupied (the other hand was holding blocks)

On the cognitive level the following aspects turned out to be important:
- In a design session sufficient time should be given for step 1: Every participant must build combination with the shapes at least once. It is important that every participant is well aware of all the options available.
- The height for the 'short click' was too long, this should be shorter.
- There is a need for a clear starting and ending point.

On the organisational level it can be concluded that:
- All participants felt a preference for the interaction case where no instructions at all were given. Taking turns did not have a positive effect on the feeling to be in control: "One after the other made us not do something together."

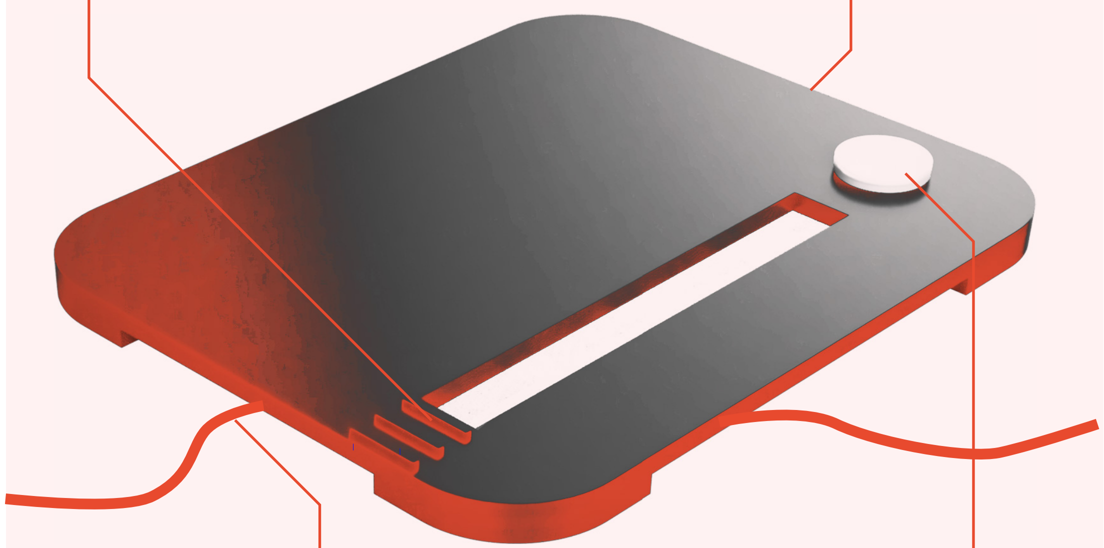
The interaction test has provided insights, which have been translated into the design improvements as presented in Figure 25. The next section shows the overview of the final design, Shape2Vibe.

The shape for the short click effect has been adjusted. The body has been adjusted to match with perception: Smaller and edgier.
Addition of small plateau, so the shape is more stable and less likely to fall.

To the silicone fuzzy shape plastic bottom has been added. This allows the expert to know where the bottom is and to know how to place the shape on the playing field

- Three embossed lines on left side of the playfield have been placed to make it clear to everyone what the beginning of the field is.

- The playfield is extended, so that the playfield is not moved by the co-designers. The shapes can be placed on the extension.



The wires connected to the vibration output have been made longer so that the vibrator outputs can be pocketed and are hands free. Moreover, they are placed underneath the board to ensure they do not get in the way of the shapes.

- The play button is attached to the playfield (right side). This way, the expert understands where the button is located at all times.

Figure 25: Design improvements after interaction test

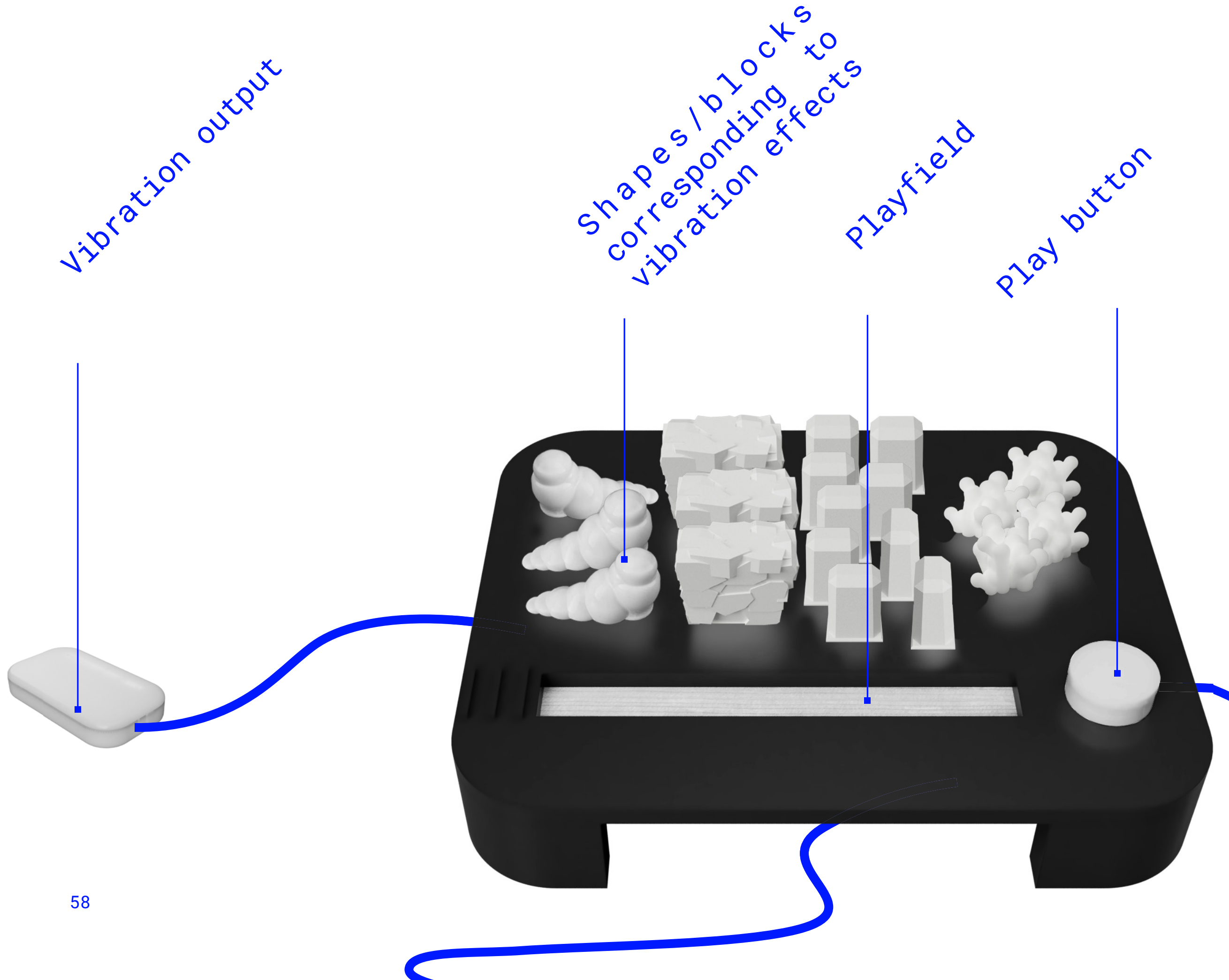
6. Shape2Vibe

This chapter describes the final design for co-designing vibrations.

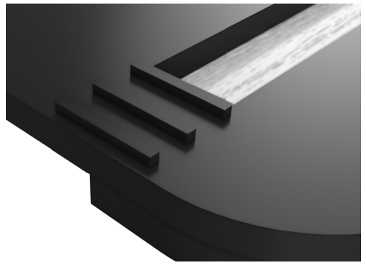
6.1 The tool

This section describes the elements of the tool as well as the most relevant details of Shape2Vibe. It elaborates not only on the elements and their functions but also on the design decisions made.

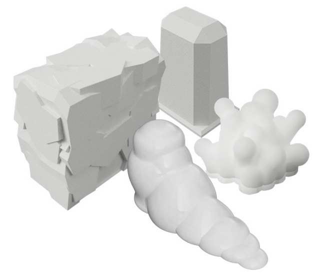
First of all, Shape2Vibe consists of a board on which the shapes/blocks are to be placed. It has been decided to make the board black. The reason for this is that this provides the largest contrast with the shapes. If any given haptic expert should still be able to see with residual vision, the shapes which are white can be distinguished from the board.



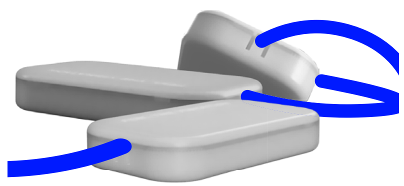
When using Shape2Vibe, it is important for users to avoid moving the board. By not moving the board, the need is eliminated for the haptic expert to constantly search for the board whenever someone has moved it. To achieve this, the board has been intentionally designed to be large enough and to give the impression of being difficult to move.



Around a table people can be seated in front of each other and may thus lose track of which side of the playfield is the beginning and which side is the end. The three embossed lines to the left of the slot mark the beginning of the playfield. the round play button marks the end of the playfield.



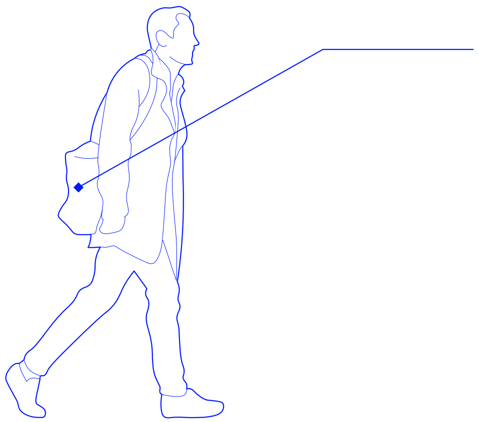
Each Shape2Vibe comprises multiple copies of the four basic shapes. The number of copies is determined by how many times they fit in the playfield. Section 5.3 describes how these shapes have been designed.



There are three vibration outputs/motors, one to be used by each participant in the co-design session. If there are more participants co-designing, more outputs can be attached. The vibration motor is a coin vibration motor, which is also applied in mobile phones (Meganburroughs, 2022). The mobile phone is the typical type of application for which vibrations are designed. The motor is stuck into a small casing making it easy to slide the output in a pocket.

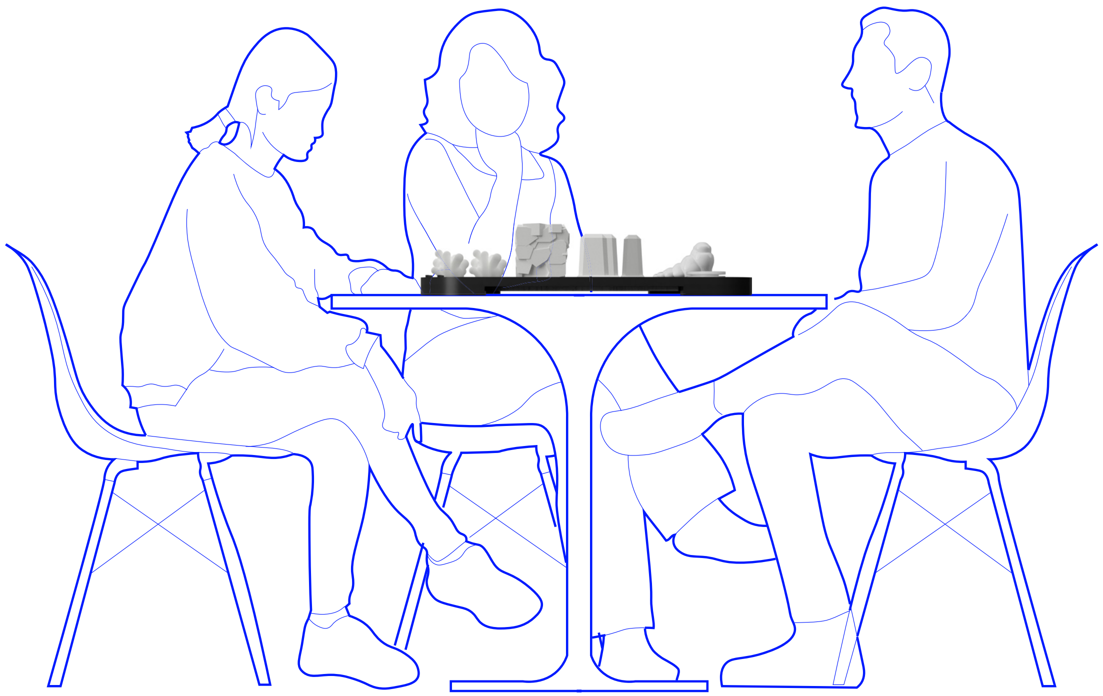
6.2 Usecase scenario

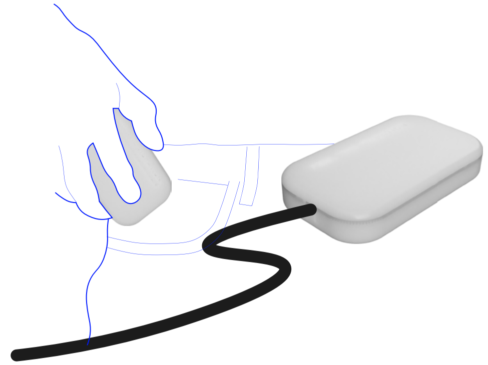
In order to illustrate how the tool is to be used by the different stakeholders, a storyboard of one example of a use case scenario is presented here.



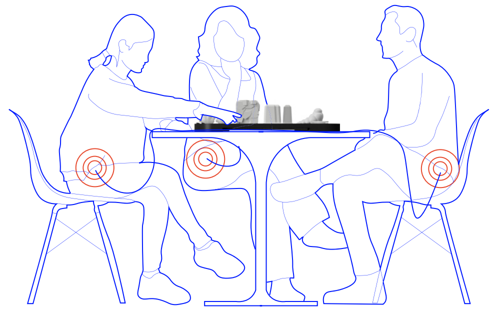
A designer ('main designer') wants to capture 'happiness' in a vibration. He decides that a haptic expert must be involved. Together with Shape2Vibe he goes to seek for help from an expert and a colleague designer.

The main designer sets up a co-design session and involves a haptic expert and a colleague of his to sit down with him around Shape2Vibe. The main designer is also one of the participants in the session.



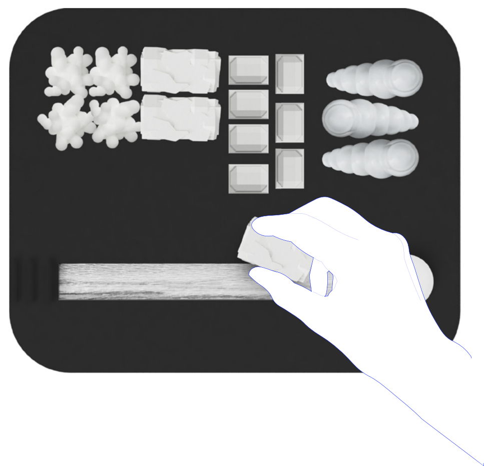


Each of the three participants gets a vibration motor to be put in the pocket. The main designer then gives an instruction about the use of Shape2Vibe.



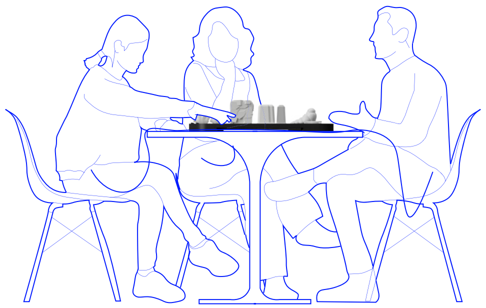
They set off by exploring the prototype: They quickly feel that when a block is placed on the playfield, a vibration corresponding to the shape of the block is played - once - in their pockets.

When the play button is pushed by one of the participants, the sequence of the blocks on the playfield is transformed - from left to right - into the corresponding vibrating rhythmical effcets via the vibration motor.

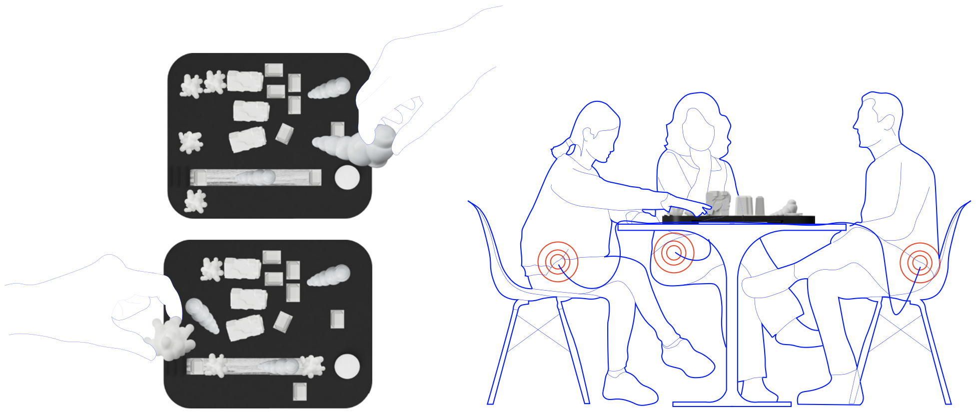


After exploring, the participants play a game: One of them builds a pattern consisting of one or more of the same blocks or of several different blocks. The participants with sight, who should only feel the vibration (eyes closed), must then try to re-build the same combination of blocks.

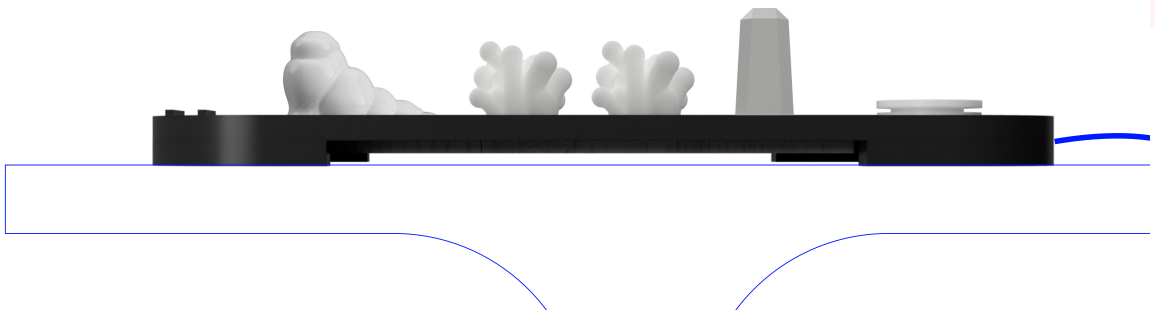
After getting familiar with all the shapes and their corresponding vibrations, the designer explains the task to be performed: “How can we embody ‘happiness’ in a vibration?”



In the beginning, the group struggles. But by repeatedly trying out different combinations and by feeling the corresponding vibration rhythms, the group is able to convey and discuss their ideas for a suitable vibration for happiness (see Figure 24 for a more detailed conversation description).



And eventually, they all agree on one particular combination of blocks that best fits the emotion of happiness. The designer then knows what fits best and is able to integrate this in the final design and realisation of the vibration.



7. Evaluation

For the evaluation of Shape2Vibe, a final test was conducted. This chapter describes the method, the results, and the discussion of the final test.

7.1 Method

In this study a prototype representing and producing vibrations has been designed and constructed. The aim was that it should be possible to be used by people with deafblindness in true co-design sessions for designing vibrations and should also be used people with deafblindness. The prototype used in the evaluation test described in this chapter, is depicted in Figure 26.

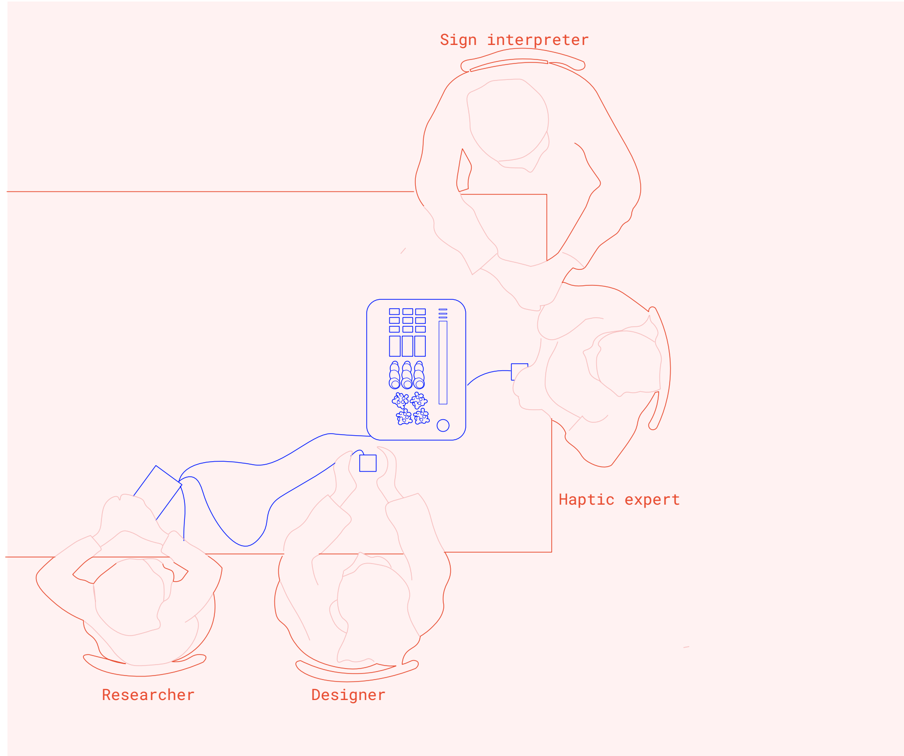


Figure 26: Test prototype and set-up

In order for this prototype to be useful for co-designing sessions, it must fulfill all requirements as layed down in the design goal. To this end, a final test was designed and carried out in order to assess whether the design goal as formulated in section 4.2 has been reached. The design goal was:

Haptic experts and other co-designers should sense an **equal division of control** while **flexibly co-designing tactons** that **intuitively enhance experiences** (as defined by a designer) through the use of **haptic perception** for supporting communication.

In order to be able to assess whether the prototype sufficiently meets the design goal, the following research questions have been formulated:

- Can each participant contribute to the design process without asking for any help?
- Can this prototype be used to co-design for different information types? Both for something 'mundane' and for emotions?
- Is control evenly distributed among the participants during the co-design process?
- Does the prototype facilitate communication during the co-design of vibration patterns?

The test scenario depicted in Figure 27, has been created to answer the questions above. The game (step 2 in the process) guarantees that participants - at the start - get familiar with the question of which vibrations correspond to which particular blocks. The game was the same as the one played in interaction experiment described in section 5.4.

In order to be able to answer the question regarding the design of different information types, the participants were asked to design for two cases. The two cases should be wide apart. The reason for this being that it is assumed that if a vibration can be designed with this prototype for two extreme cases, it will work for all cases in between the two extremes. So, it was decided that in case 1 a fire alarm should be designed, and in case 2 a smile: A fire alarm is a mundane example, which most likely is best suited for the design of an alerting vibration. The other example (the smile) is a rather abstract emotion which is expected to have a calm vibration design.

Observations made during both cases pertain to the question how frequently each participant uses the prototype. The following hypothesis has been formulated: If every participant has had approximately the same number of touchpoints with the blocks, the participants have all been in roughly the same degree of control. The same degree of control is assumed to be a clear indication of the degree of collaboration. The semi-structured (group) interview (step 5) with each of the participants provided more qualitative insight into why this may or may not be the case.

The test was held at the haptic expert's home, for practical reasons. Because, the haptic expert can only communicate via a sign interpreter, such an interpreter (who had been arranged by the expert) was invited to take part in the final test as well, together with the haptic expert and the designer. Apart from these three participants, the researcher also played an active role: The researcher gave the instructions about the prototype and the game, and also made the observations of the co-design session. In addition, after the two cases, the researcher lead the semi-structured interview.

The test was recorded, transcribed and analysed. The data was analysed according to the method of re-occurring themes (Clarke & Braun, 2016). The deductive themes as defined prior to the evaluation of the prototype are: Usability, flexibility, collaboration, and communication support.

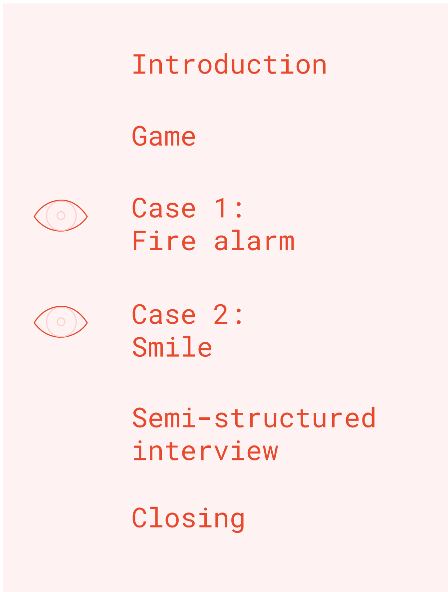


Figure 27: Test activities overview

7.2 Results

This section shows the results grouped according to the themes: Usability, flexibility, collaboration, and communication support. During the analysis, yet another theme, about the game element, emerged: The role of the game.

Usability

It was initially intended that the sign interpreter would also join the co-design session. However, after a brief consultation with the expert and the interpreter, it was decided that it was practically impossible for the sign interpreter to both communicate with the expert and to join the co-design session. Therefore, the final test involved two participants only, namely the haptic expert and the designer.

Apart from the sign interpreter not being able to join the co-design session, all participants were able to use the prototype as described in section 6.1. After the two cases, both the haptic expert and the designer agreed that it was clear to them how the prototype should be used. However, when being asked - after the cases - whether any basic vibrations were missing the haptic expert remarked:

> "I would have liked it if there had been a block that would represent three short vibrations." - Haptic Expert

So, apparently, it was not clear to the haptic expert that by making a combination of three short clicks, it would have been possible to create the effect of three short vibrations.

To conclude, the prototype is usable by all participants, but it should be explicitly made clear in step 1 how the creation of combinations works. Subsequently, it should also be made an explicit part of the game (step 2) to re-build a vibration consisting of a combination of blocks.

Flexibility
The participants agreed that, as could have been expected, the ‘smile’ case (case 2) was more difficult to design for than the ‘fire alarm’ (case 1). The participants felt that the blocks themselves do not support the deeper levels of the emotion well enough.

> “If you laugh really hard, you have very intense vibrations going up and down a lot. Or if you laugh a little bit, then it should not be as intense. Now it only indicates one level, so I find that a bit tricky.”- Haptic Expert

> “I think we agreed on the fire alarm more rapidly. We needed to discuss a bit more on how the vibration should feel for the smile. So more communication was needed when designing the smile than just the blocks.” - Designer

Furthermore, the prototype (more specifically the playfield of the prototype) has been constructed in such a way that only a maximum of 4-8 blocks (depending on the sizes of the blocks in question) can be combined. This enabled the participants to only design a vibration with a specific time frame (maximum 5 seconds). When designing for the fire alarm, the designer expressed the explicit wish to be able to specify what should happen after these 5 seconds.

> “I’m curious to what happens after that (after 5 seconds), is the three times the alert the most important thing here? Or should there be an interval and then three times again? Or should it vibrate continuously?”. - Designer

Should, for this reason,the playfield be constructed in such a way as to allow for more than 5 seconds? The answer is: No, because it is impossible to introduce a very long playfield due to physical ergonomics reasons.

Moreover, with the current playfield in the prototype, the desired discussion about the vibration arose, while at the same time the creative flow was not interrupted. Therefore, it can be said that the prototype works flexibly enough not to interrupt the creactive flow on a physical ergonomics point of view.

On a cognitive ergnomics point of view, it can be concluded that the blocks do not provide enough flexibility to cater for all levels of information types.

Collaboration
From the analysis of the group interview (with reference to both cases) it appeared that all participants had felt in control.
In Table 1 the number of interactions (touchpoints) each participant had with the prototype is shown. The hypothesis as stated in section 7.1 (page 65) was: If all participants have approximately the same number of touchpoints with the blocks, the participants are all in roughly the same degree of control. From the results presented in the table below, it can be concluded for case 1 that both participants had the same number of touchpoints, as opposed to case 2. Along the line of the hypothesis, it could be said that in case 2 there is a difference in degree of control between the two participants. However, the ramp down, which had been proposed by the designer and not by the expert, is represented in the final rhythm of case 2 nevertheless. This is proof that the influence of the designer is clearly present and so there has been equal control, even though the ramp down was initially not proposed by the expert at all. Also the general number of touchpoints of the expert is substantially higher than that of the designer, which is an indication that - in any case - the expert participates at least as much as the designer.

Case 1: Fire alarm

	Short click	Alert	Fuzzy	Ramp up	Ramp down
Haptic Expert		3			
Designer	2	1			
Final Rhythm		3			

Case 2: Smile

	Short click	Alert	Fuzzy	Ramp up	Ramp down
Haptic Expert	2	1		2	
Designer				1	1
Final Rhythm	2			1	1

Table 1: Participant interaction in terms of number of touchpoints with prototype. The final rhythm (combination of blocks) is the rhythm both participants agreed upon.

Asking specifically about the collaboration in the semi-structured interview after the two cases, the participants agreed that they had felt in control:

> “I think it works particularly well that we could both communicate with the blocks.” - Designer

> “Yes, I can feel what she is doing. And I feel what I am doing. If the designer uses a certain block or me. I can feel that very well.” - Haptic Expert

To conclude: The prototype entails communication about the ideas for vibrations by means of the blocks (each representing a particular vibration), thus making sure that all the participants are on the same (haptic) level of communication. This keeps control division equal.

Communication support

During the final test, the participants really used the prototype as a means to support the communication of their ideas for vibrations. As already mentioned in section 5.4, the prototype appeared, again, very inviting to use. Again, during this session, ideas were communicated with the blocks:

> “ So maybe if those vibrations go like that [picks up ramp up block] then you feel that the vibration conveys happiness.“ - Haptic Expert

> “..The vibration reflecting sadness now [ramp up - ramp down plays], and if you change direction of the block, the vibration will be happiness [ramp down - ramp up plays].” - Designer

Figure 28 shows a photo taken by the researcher during the test. What is striking to see is that while the designer (left) is communicating her idea for a vibration, the sign interpreter (right) translates what the designer is saying. The haptic expert (middle) feels what the designer is saying, at the same time holding the motor in her hand (blue circle).

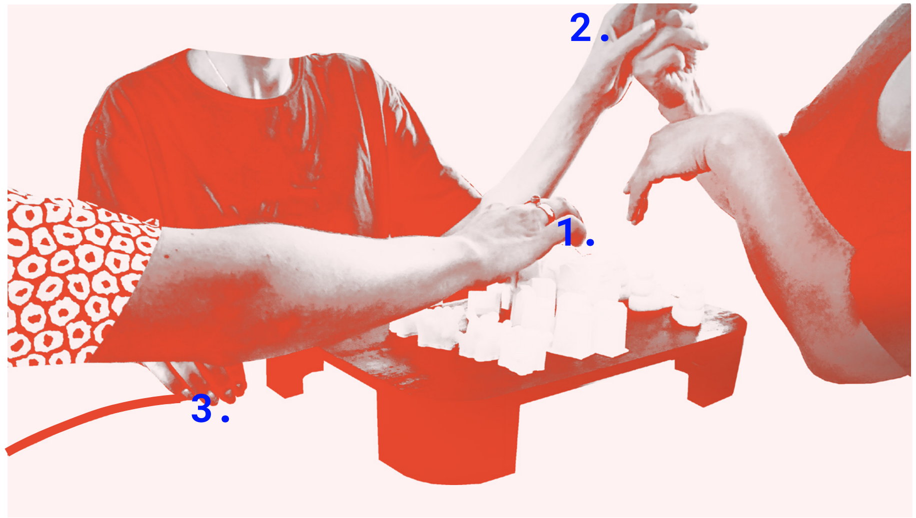


Figure 28: Haptic Expert (middle) feeling what the designer (left) is trying to communicate with the blocks (1), by feeling the translation (2) by the sign interpreter (right) and by feeling the vibration of the idea (3).

The role of the game element

The game (step 2) that was played before the two cases is crucial for the design process. The game, which had been specially constructed for this project, is a haptic variant of Mastermind: One participant builds a vibration with the blocks in the playfield: The proposal. Other participants who have sight are not allowed to see which proposal is placed in the playfield. They can, however, feel which blocks are proposed by feeling the vibrations. Subsequently, the participants have to re-create the proposed, previously built vibration from memory.

The game is a pre-requisite in order for the co-design to take place succesfully. Firstly, because - as stated in section 7.1 - it helps the participants to get familiar with the vibrations corresponding with the blocks. Secondly, the game is also a necessary step because if anything should be still be unclear about the prototype, it will be filtered out during the game. Consequently, any unclearity or confusion does not interfere with the creativity in the co-design phase.

Thirdly, the game helps the participants to loosen up. The more the participants feel team safety, the more fluent the teamwork goes (Edmondson, 1999).

And last, but not least, the importance of the role of the haptic expert is magnified in this game. This became clear during the test: The designer failed twice to re-create the vibrations. The haptic expert, on the other hand, was able to easily and successfully re-build the vibration. In the semi-structured interview the designer mentioned how much of an eye-opener the game was to her:

> "I think the biggest eye-opener for me was the fact that I'm not very good at feeling. Significantly worse than the haptic expert." - Designer

It can be concluded that the game is an essential element when using the final design.

7.3 Discussion

During case 2 (the 'smile'), an issue arose: The vibration motor stopped working. This lead to a shift of communication about the vibrations, namely from feeling the vibrations to talking about them. Previously, in case 1, when the vibration motor had worked well, the participants relied on the tactile feedback from the vibration motor to guide their interactions with the prototype. So, in fact, they had built up knowledge about which vibration corresponds to which block. With the absence of vibrations in case 2, verbal communication became the primary means of conveying information about the vibrations. This change from haptic to verbal communication may have been one of the reasons why the participants considered case 2 more difficult.

The design of the shapes in the prototype had been based primarily on direct visualisations of the vibrations (section 5.3 on page 49). This approach worked very well for conveying concrete information such as the fire alarm, but it posed some difficulty when attempting to represent a more abstract concept, such as a subtle emotion. To address this limitation, further studies should be conducted to explore whether the shapes/blocks used in the co-design process should primarily be association based. By investigating a variety of abstract design cases, researchers can gain more insight into alternative approaches that could perhaps more effectively represent abstract concepts and enhance the possibility to communicate about them.

Throughout the entire process of the final test, the researcher (of the current project) was present to assist the participants and to answer any questions they might have. This presence played a crucial role in aiding the participants' understanding of the prototype and addressing their inquiries. Without the researcher's guidance, the participants might have encountered greater difficulty in navigating the prototype and comprehending its functionality. However, ultimately the prototype must be self-explanatory and one must be able to use it independently from the researcher. As a consequence, it is important to further consider and investigate in what way the role of the researcher can be reduced or, for that matter, even completely eliminated.

It is worth noting, on the basis of remarks by one of the participants, that the game aspect of the prototype may have evoked feelings of competition among the participants. While competition can be beneficial in certain contexts, it does not align with the collaborative nature of a co-design process. To create an even more suitable environment for collaboration, an alternative game design that encourages participants to work towards a common goal should be explored in future research. By fostering cooperation rather than competition, the co-design process can promote an even more harmonious approach.

8. Conclusions & Recommendations

This chapter presents the main findings in terms of general conclusions and by summarising the contribution of this research to inclusive co-desing methodology.

8.1 General conclusions

This thesis has researched the possibilities for a tacton co-design process with haptic experts (people with deafblindness). Moreover, a working and suitable tool and method have been designed and constructed with which the participants can communicate various ideas for creating meaningful vibrations in a co-design process. Communication is supported by embodiments of four basic vibrations, with which a co-design group is able to create rhythms by combining the basic vibrations.

The combination of Vibviz, the haptic motor library, and the clay modelling and building experiment of section 5.3 has turned out to be, in principle, a fruitful approach for the shaping of vibrations. Clay modeling seems to be an extremely interesting method for investigating perceived shapes for vibrations experiment and can be used as a source of inspiration for future studies.

Compared to turn taking instructions, free format designing (no instructions) leaves all participants in a co-design session equally in control. This method allows each participant to have equal control and allows for a collaborative environment. In addition, Shape2Vibe is inviting to use according to the participants. This is proven in section 5.4.

Shape2Vibe works well as a communication support during the co-design process. Ideas are communicated through the blocks. Being able to communicate through the blocks leaves co-design participants at the same level of control. The four shapes of te blocks designed as the embodiment of basic vibration effects from the haptic motor library greatly contribute to a co-design session, at least for everyday design cases (such as a fire alarm). However, more communication is needed for co-designing vibrations for emotions, and more association-based cases. Modelling emotions in a vibration needs a more layered approach. For instance, emotions are very much context-based and operate on different levels (e.g. roaring with laughter versus smiling). This has been confirmed by the evaluation test done in Chapter 7.

A by-product of this thesis is that the game developed for the method has been received very positively by all participants during the test. Furthermore, it is a nice way to start a co-design session: It loosens up the participants, filters confusion of the prototype out of the co-design phase, and magnifies the role of the haptic expert.

Overall, Shape2Vibe helps other designers to co-design vibrations with haptic experts, and this way the current research contributes towards more inclusive designs.

8.2 Design recommendations

This section presents recommendations for improvement of the design of Shape2Vibe.

During the evaluation an Arduino prototype was used where the researcher would manually play the vibrations corresponding to the blocks/shapes. As stated in 7.3, Shape2Vibe should ideally be used on its own, without external aid. So, it should be automatisated. For automatisation the following methods could be employed:
- **Webcam and colour mark recognition**: This method entails computer software that enables colour recognition. Each shape category must get a unique colour. The webcam is placed on a fixed frame. This way, the software is able to recognise where and which shape is placed on the playfield. The downside of this method is that it takes much time to develop in detail. In addition, for this method to work, a frame would be around the playfield, for the webcam to be placed in. This might hinder the co-designers in participating. An example for the webcam-set up can be seen in Figure 29.
- **Copper tape and resistors**: Fifteen Arduino pins must be connected to a place on the playfield (see Figure 30). Each shape category has its own unique resistor. The copper tape sees to it that the electrical circuit closes. This way the Arduino is able to read values when a shape is placed on the playfield. Because each shape has its own resistor, the Arduino reads unique values , one for each shape. However, it might be error prone, because the copper needs to make proper contact in order for the circuit to be closed.

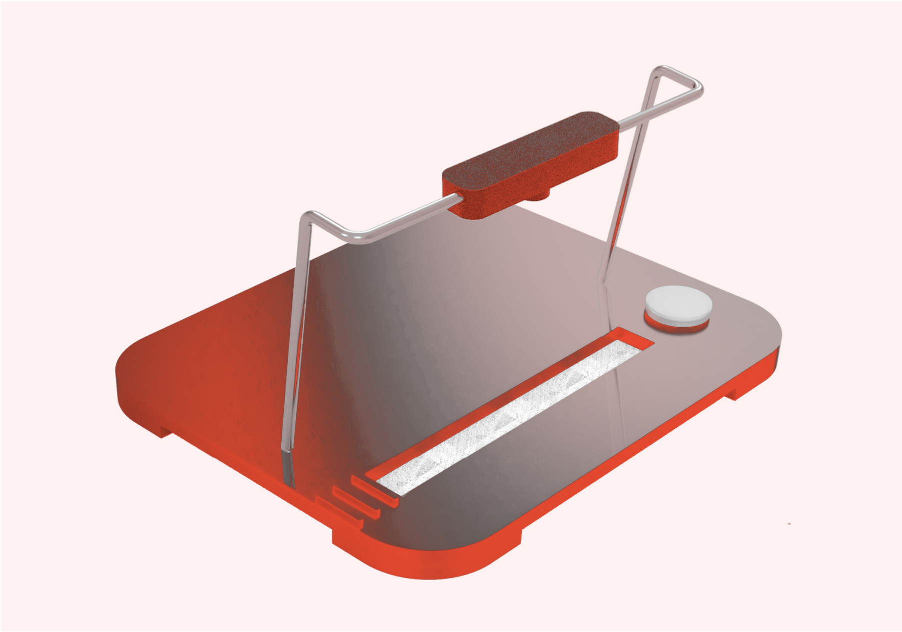


Figure 29: Webcam recongnition set-up

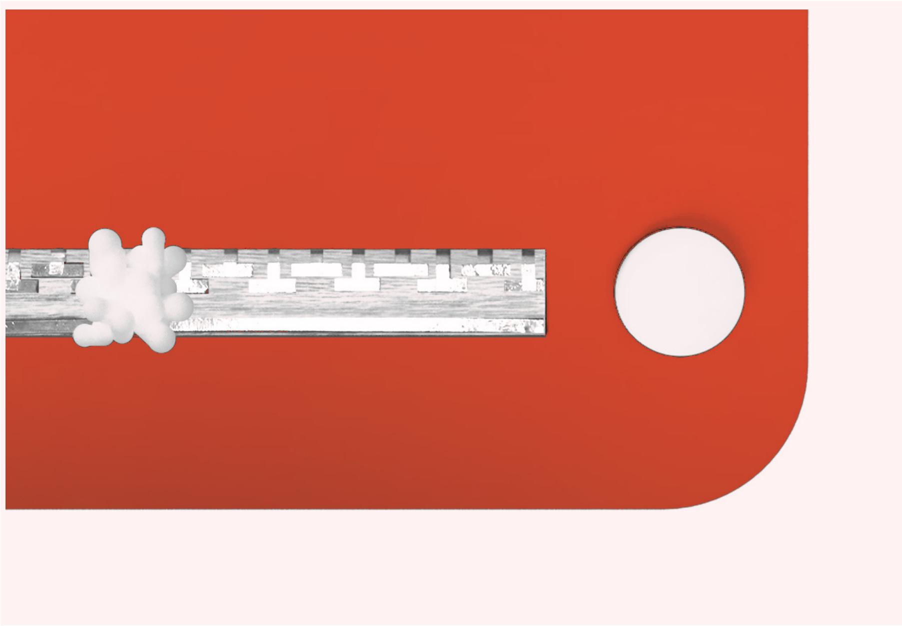


Figure 30: Copper tape and resistor set-up

Further study into automatisation would have to be done in order to make Shape2Vibe a robust self-sufficient product. Ultimately Arduino should be replaced by something more stable.

Moreover, during this study, the function of being able to record a designed vibration during the co-session was foreseen to be tested. However, this would have been a very useful functionality. Figure 31 shows a proposed function for recording a designed vibration that is to be reconsidered later on in the process. Adding the recording functionality to Shape2Vibe would enable co-designers to fixate on a vibration design and set it aside for a moment ,to come back to when wanting to compare vibration designs.

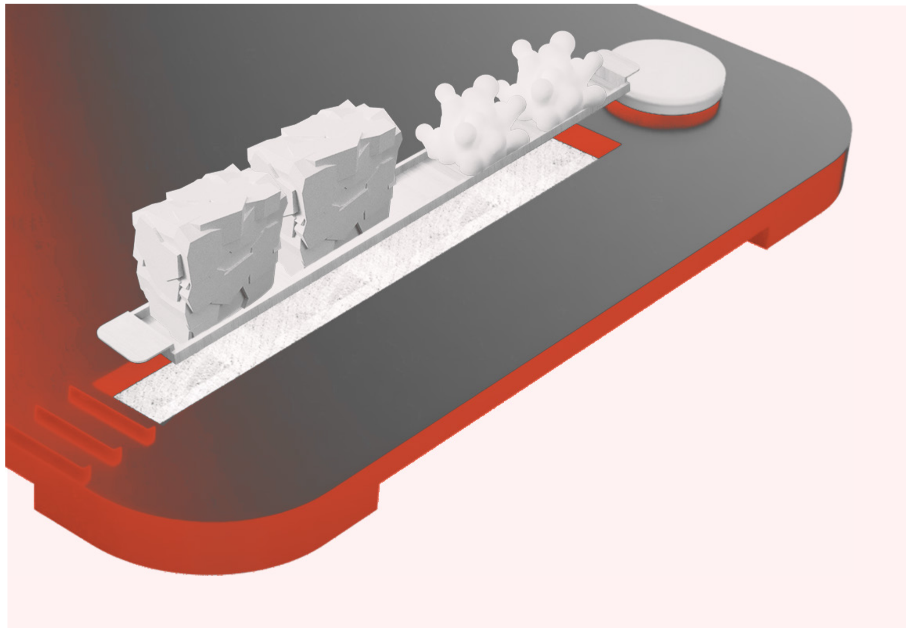


Figure 31: Recording recommendation

8.3 Research recommendations

This section presents the recommendations for future research into co-designing without vision and hearing.

During the limited time of this project, the clay and modelling experiment was informally carried out. No instructions were given as to how the participants should clay model the vibrations (close to the vibrations or more association based). So the results could only be used as an inspiration source for developing the shapes. More structured research with more participants would have to be carried out in order to be able to systematically conclude whether shapes correspond to certain effects.

The design of the shapes in the prototype had been based primarily on direct visualisations of the vibrations (section 5.3 on page 49). This approach worked well for conveying concrete information such as the fire alarm, but it posed some difficulty when attempting to represent a more abstract concept, such as a subtle emotion. To address this limitation, further studies should be conducted to explore whether shapes that are more association based result an 'easier' co-design process for abstract cases.

Furthermore, it has not been tested in the current project whether the prototype is understandable - and thus usable - without the researcher being present. Such studies could employ the System Usability Scale (SUS) to evaluate the overall usability of Shape2Vibe.

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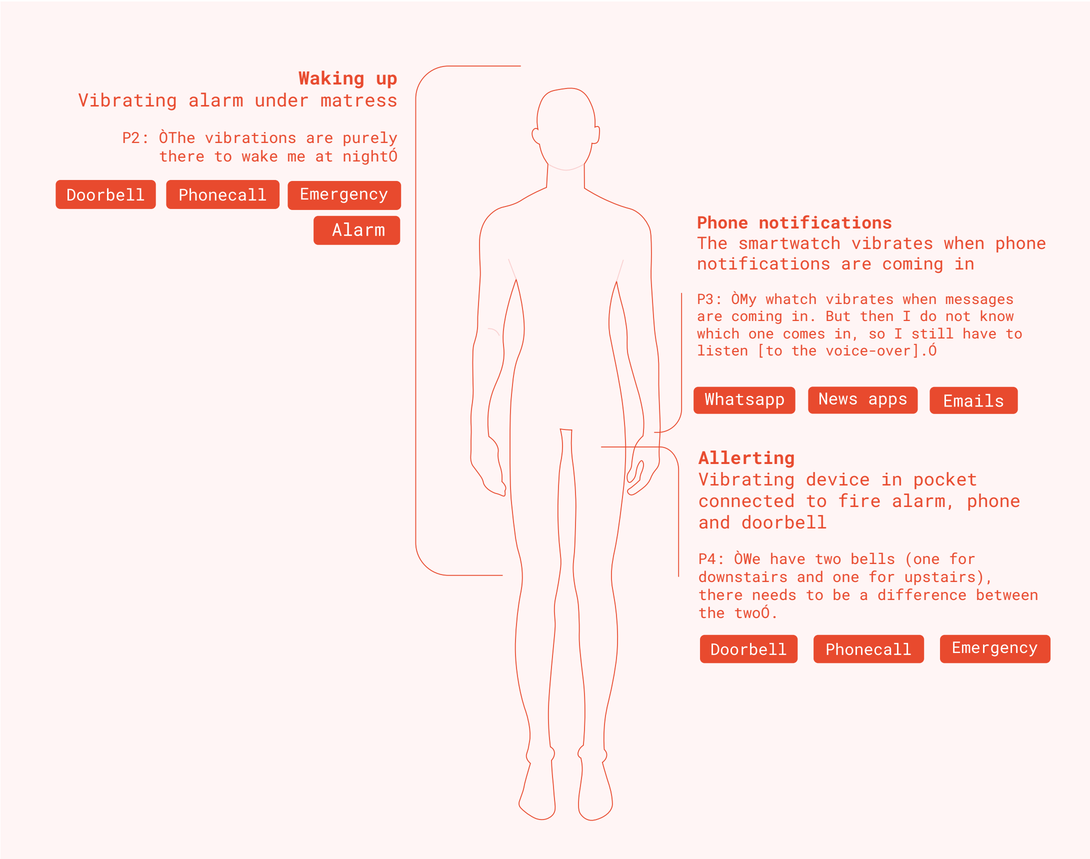
10. Appendices

A: Haptic Expert’s associations with vibrations
B: Haptic motor library analysis
C: Detailed results interaction test

A: Haptic Expert's associations with vibrations



B: Haptic motor library analysis

Some effects are a combination of several effects (e.g. effect #27: Double click strong is two times effect #1). The shapes (each representing an effect) can be placed multiple times on the playfield. Therefore, some effects are excluded from the analysis.

1 - Strong Click - 100%
2 - Strong Click - 60%
3 - Strong Click - 30%
4 - Sharp Click - 100%
5 - Sharp Click - 60%
6 - Sharp Click - 30%
7 - Soft Bump - 100%
8 - Soft Bump - 60%
9 - Soft Bump - 30%
10 - Double Click - 100%
11 - Double Click - 60%
12 - Triple Click - 100%
13 - Soft Fuzz - 60%
14 - Strong Buzz - 100%
15 - 750 ms Alert 100%
16 - 1000 ms Alert 100%
17 - Strong Click 1 - 100%
18 - Strong Click 2 - 80%
19 - Strong Click 3 - 60%
20 - Strong Click 4 - 30%
21 - Medium Click 1 - 100%
22 - Medium Click 2 - 80%
23 - Medium Click 3 - 60%
24 - Sharp Tick 1 - 100%
25 - Sharp Tick 2 - 80%
26 - Sharp Tick 3 – 60%
27 - Short Double Click Strong 1 – 100%
28 - Short Double Click Strong 2 – 80%
29 - Short Double Click Strong 3 – 60%
30 - Short Double Click Strong 4 – 30%
31 - Short Double Click Medium 1 – 100%
32 - Short Double Click Medium 2 – 80%
33 - Short Double Click Medium 3 – 60%
34 - Short Double Sharp Tick 1 – 100%
35 - Short Double Sharp Tick 2 – 80%
36 - Short Double Sharp Tick 3 – 60%
37 - Long Double Sharp Click Strong 1 – 100%
38 - Long Double Sharp Click Strong 2 – 80%

39 - Long Double Sharp Click Strong 3 – 60%
40 - Long Double Sharp Click Strong 4 – 30%
41 - Long Double Sharp Click Medium 1 – 100%
42 - Long Double Sharp Click Medium 2 – 80%
43 - Long Double Sharp Click Medium 3 – 60%
44 - Long Double Sharp Tick 1 – 100%
45 - Long Double Sharp Tick 2 – 80%
46 - Long Double Sharp Tick 3 – 60%
47 - Buzz 1 – 100%
48 - Buzz 2 – 80%
49 - Buzz 3 – 60%
50 - Buzz 4 – 40%
51 - Buzz 5 – 20%
52 - Pulsing Strong 1 – 100%
53 - Pulsing Strong 2 – 60%
54 - Pulsing Medium 1 – 100%
55 - Pulsing Medium 2 – 60%
56 - Pulsing Sharp 1 – 100%
57 - Pulsing Sharp 2 – 60%
58 - Transition Click 1 – 100%
59 - Transition Click 2 – 80%
60 - Transition Click 3 – 60%
61 - Transition Click 4 – 40%
62 - Transition Click 5 – 20%
63 - Transition Click 6 – 10%
64 - Transition Hum 1 – 100%
65 - Transition Hum 2 – 80%
66 - Transition Hum 3 – 60%
67 - Transition Hum 4 – 40%
68 - Transition Hum 5 – 20%
69 - Transition Hum 6 – 10%
70 - Transition Ramp Down Long Smooth 1 – 100 to 0%
71 - Transition Ramp Down Long Smooth 2 – 100 to 0%
72 - Transition Ramp Down Medium Smooth 1 – 100 to 0%
73 - Transition Ramp Down Medium Smooth 2 – 100 to 0%
74 - Transition Ramp Down Short Smooth 1 – 100 to 0%
75 - Transition Ramp Down Short Smooth 2 – 100 to 0%
76 - Transition Ramp Down Long Sharp 1 – 100 to 0%
77 - Transition Ramp Down Long Sharp 2 – 100 to 0%
78 - Transition Ramp Down Medium Sharp 1 – 100 to 0%
79 - Transition Ramp Down Medium Sharp 2 – 100 to 0%
80 - Transition Ramp Down Short Sharp 1 – 100 to 0%
81 - Transition Ramp Down Short Sharp 2 – 100 to 0%
82 - Transition Ramp Up Long Smooth 1 – 0 to 100%
83 - Transition Ramp Up Long Smooth 2 – 0 to 100%
84 - Transition Ramp Up Medium Smooth 1 – 0 to 100%

85 - Transition Ramp Up Medium Smooth 2 – 0 to 100%
86 - Transition Ramp Up Short Smooth 1 – 0 to 100%
87 - Transition Ramp Up Short Smooth 2 – 0 to 100%
88 - Transition Ramp Up Long Sharp 1 – 0 to 100%
89 - Transition Ramp Up Long Sharp 2 – 0 to 100%
90 - Transition Ramp Up Medium Sharp 1 – 0 to 100%
91 - Transition Ramp Up Medium Sharp 2 – 0 to 100%
92 - Transition Ramp Up Short Sharp 1 – 0 to 100%
93 - Transition Ramp Up Short Sharp 2 – 0 to 100%
94 - Transition Ramp Down Long Smooth 1 – 50 to 0%
95 - Transition Ramp Down Long Smooth 2 – 50 to 0%
96 - Transition Ramp Down Medium Smooth 1 – 50 to 0%
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98 - Transition Ramp Down Short Smooth 1 – 50 to 0%
99 - Transition Ramp Down Short Smooth 2 – 50 to 0%
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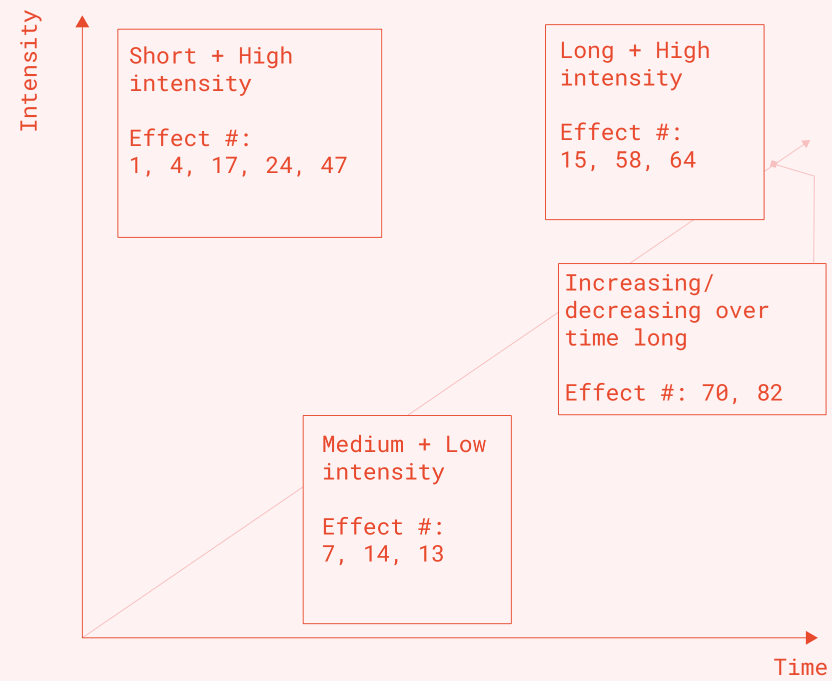
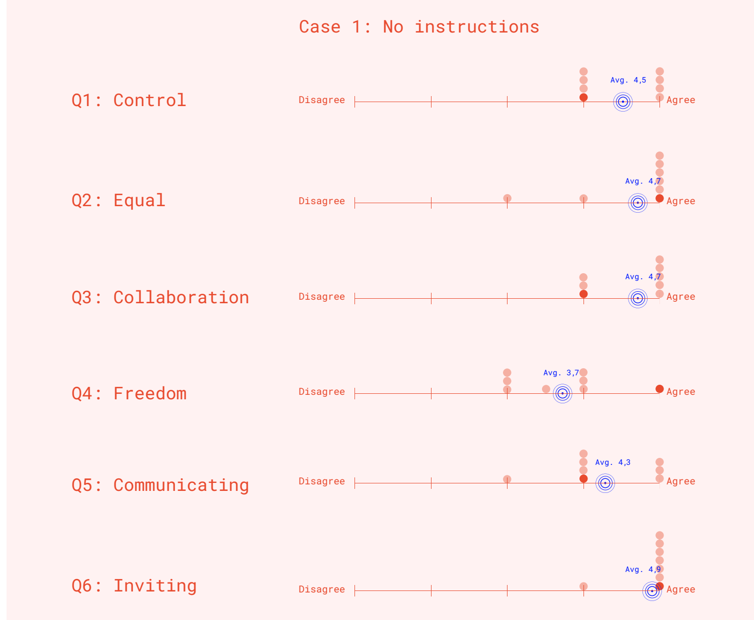
107 - Transition Ramp Up Long Smooth 2 – 0 to 50%
108 - Transition Ramp Up Medium Smooth 1 – 0 to 50%
109 - Transition Ramp Up Medium Smooth 2 – 0 to 50%
110 - Transition Ramp Up Short Smooth 1 – 0 to 50%
111 - Transition Ramp Up Short Smooth 2 – 0 to 50%
112 - Transition Ramp Up Long Sharp 1 – 0 to 50%
113 - Transition Ramp Up Long Sharp 2 – 0 to 50%
114 - Transition Ramp Up Medium Sharp 1 – 0 to 50%
115 - Transition Ramp Up Medium Sharp 2 – 0 to 50%
116 - Transition Ramp Up Short Sharp 1 – 0 to 50%
117 - Transition Ramp Up Short Sharp 2 – 0 to 50%

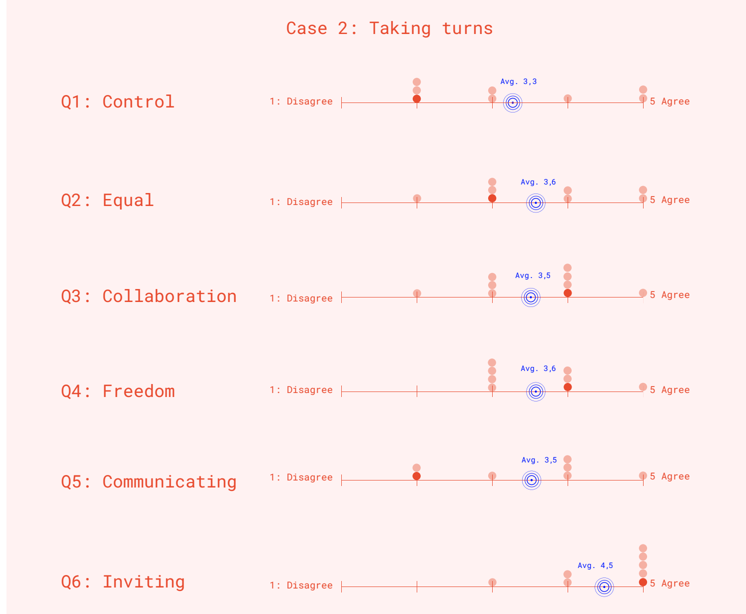
The ultimate selected effects were based on how easily they can be distinguished from one another.

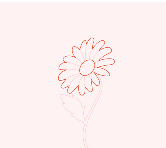
Analysis of Haptic motor library



C: Detailed results interaction test







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