UNIVERSITY OF TWENTE.

**Faculty of Electrical Engineering,
Mathematics & Computer Science**

Social Touch

Investigating the effect of mediated social touch on social presence

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M.Sc. Thesis
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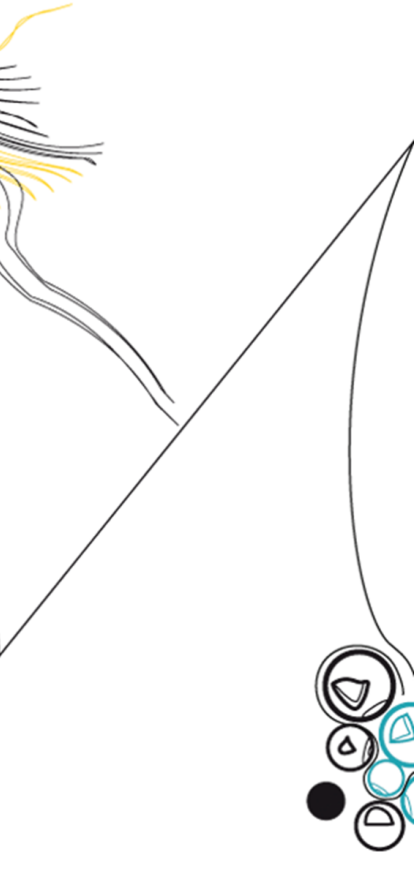

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The first time I watched Arnold Schwarzenegger's "No one is a self-made man" speech, it made a tremendous impact on me. There is no one in the world who truly does all the work alone. There is always someone out there in the background who has always helped you, no matter how big or small. When you are doing a thesis, it may often seem as if you are doing everything alone. But that is far from the truth. When I was doing this thesis, there were so many people in my life who, personally, professionally, and academically have helped me successfully complete it. This section is dedicated to those bright stars without whom I would have lost my way.

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ABSTRACT

In the last pandemic, people understood the importance of physical social interaction and with it realized the importance of touch. A loss of touch for a prolonged period was found to be detrimental to one's mental health. Mediated touch technologies proved to be useful since people could communicate social touch easily over the internet. However, more research in terms of presence and empathy was required. This study aims to answer, "How does a vibrotactile sleeve affect the perception of presence with the other during remote communication in affective relationships?". Concepts such as touch starvation, social touch, mediated touch, and social connectedness were taken as starting points. Furthermore, various state-of-the-art devices regarding mediated touch are also discussed. Based on these technologies and the concepts, a design criterion for building the interaction and setup was made, followed by the methodology for conducting the experiment. 22 pairs of individuals in affective relationships with each other participated in the study. While the implementation succeeded in providing comfort, it could not provide conclusive results for perception of presence. As such, various reasons, insights, and limitations are discussed which could help for future research.

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1 INTRODUCTION

COVID-19 was a devastating time. One visible thing was that everyone started working from home. This was truly insightful for many. People understood how they could efficiently optimise their workplaces for better productivity. While workplace efficiency is an important thing to consider, social interaction is also an equally important aspect of mental health since humans are social beings [1]. To overcome this problem of interaction, people resorted to online meetings through video conferencing software like Skype, Zoom, Teams, etc. People had online meetings, met at virtual cafes, and even attended live virtual concerts. Despite these solutions, there was one problem the virtual world had brought. The problem was such a mundane event, that people might have overlooked it.

In daily life, people come across many others with whom they interact face-to-face. They interact with them verbally and non-verbally. Video calls can convey both these interactions, but it lacks a major sensory aspect of daily life interaction. In the physical world, one engages in a conversation using 3 senses – visual, auditory, and somatosensory (touch) [2]. Visual and auditory senses are predominant in communication, but touch is an equally essential part of human interaction and is therefore unavoidable. Touch not only communicates information but also emotion. People touch to comfort others, persuade someone, express intimacy, build a closer relationship or even build anxiety [3]. While the types of touch depend on culture, most touches are reserved for one's close relations – family, friends, and partners [4,5]. For example, a mother embracing a crying child for comfort or a hug between two friends who met after a long time. As these examples suggest, touch also communicates emotions directly. Therefore, a lack of touch is a truly dreadful situation.

So, the question now stands, is it even possible to comfort your loved ones over a video call? Naturally, this question is too vague to answer right away but should be clear by the end of this thesis. There is an entire science to conversing with humans called computer-mediated communication. Therefore, these aspects need to be studied as well to understand the purpose and concept of this thesis. The upcoming sections shall see what all factors affect such a study.

1.1 RESEARCH QUESTIONS

This study explores the effect of a vibrotactile sleeve with respect to its user's emotions. Since, studying a range of emotions in a mediated communication is too wide of a scope for a master thesis, here, only the feeling of presence is observed.

Therefore, the primary goal of this study is to answer:

> *How does a vibrotactile sleeve affect the perception of presence with the other during remote communication in affective relationships?*

The secondary goals help understand the context of this study. Therefore, they are as follows:

1. What is meant by the perception of presence?
2. How to measure the perception of presence?
3. What is the state of the art in vibrotactile sleeves?
4. How does this setup affect people in terms of social presence?
5. What added effect does the vibrotactile sleeve bring to the remote communication?

2 TOUCH STARVATION

During social distancing, people had no means of physical contact with others, except if they lived with someone. This has majorly affected people who lived alone. They could potentially face the issue of touch starvation or hunger. Touch starvation is a condition that happens when people are denied physical social interaction with colleagues, friends, or family. In such a scenario, the mind becomes stressed, anxious, or in extreme cases, even depressed [6]–[8]. It is common knowledge that the skin is the largest social organ of the human body, it responds to both good and bad sensations [9]. Good sensations, like a hug, trigger the brain to release oxytocin which would usually reduce anxiety and stress levels. But in touch starvation, the lack of oxytocin leads to stress which triggers the brain to release cortisol, which in turn, increases your heart rate, blood pressure, muscle tension and breathing rate and affects your immune and digestive system [10].

Studies show that touch hunger was prevalent in the nursing or medical field for the duration of the pandemic. Usage of personal protective equipment (PPE) like masks and gloves led to creating a physical barrier between the patients and healthcare workers [8]. Another instance of touch starvation and social distancing was seen during the outbreak of Ebola. It was observed that isolating the affected people caused the nurses' ability to connect and comfort the patients during times of distress [11].

A greater proportion of touch starvation has been studied between infants and their caregivers than in adults [12]. In a study measuring differences in touch children received by maternal care versus children in institutional care or of clinically depressed mothers, it was observed that the latter receive significantly less affectionate touch. These children were later observed to have cognitive and neurodevelopmental delays [13,14] compared to their peers. These delays often persist into early adolescence [15]. Another study [16] observes psoriasis patients who assumed people would not touch them had higher depression scores compared to psoriasis patients with no such assumption. Likewise, touch starvation especially of the affective kind has been observed to cause body image dissatisfaction and eating disorders as well [17].

3 MEDIATED TOUCH

Mediated touch is a method to socially touch people through a computer. This is useful in situations where two people live apart and are unable to touch each other physically. This touch is conducted using an intermediary device called haptics devices. Haptics is the science of transmitting and understanding information through touch [18]. Therefore, haptic devices are devices that imitate touch. It allows its user to feel the sensations of touch. It is important to know that sense of touch is not just limited to skin-skin contact. Sense of touch also includes the sense of body movement and awareness of limbs, for example, the force felt by your shoulders while carrying a backpack. These two main categories of touches are called tactile and kinaesthetic feedback. The feedback sensed by the skin is called tactile feedback. They engage the thermoreceptors and mechanoreceptors by variating pressure, temperature, vibration and/or displacing skin to give the effect of touch [3]. On the other hand, kinaesthetic feedback or force feedback applies force to its user's body [19].

Fig. 1 shows different types of haptics categorized by the type of effect they produce. Section 6 shall focus on finding the suitable type of haptics for this study.

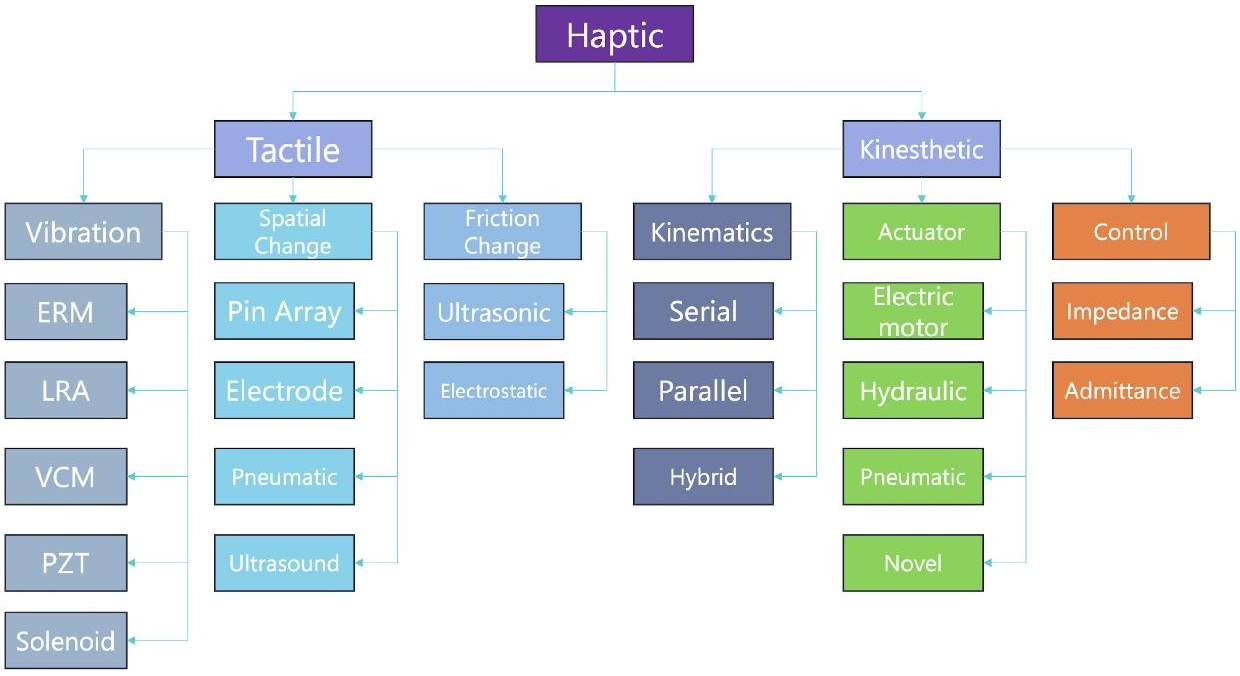


Figure 1. Types of haptic feedback [20]

3.1 AFFECTIVE HAPTICS

Affective haptics is a branch of mediated touch that focuses on creating haptic devices that can capture, sense or display emotions through touch [21]. It is a multidisciplinary field that spans affective computing, haptic technology, as well as user experience. Affective computing deals with methods to display, elicit, detect, and communicate emotions. Haptics provides a bidirectional communication channel for touch between two people. Finally, user experience measures the overall quality of user experience for using haptics to communicate emotions.

Affective haptics has been used in a multitude of fields ranging from personal to professional instances alike. For example, in healthcare, they have been used to treat depression or anxiety [22], provide assistive technology and augmented communication systems for children with autism [23] and have also been used in psychological health applications to determine the emotional state of a patient [24]. In other instances, affective haptics has also been proved to be useful in e-learning [25], collaborative gaming [26], negotiation [27], and social and interpersonal communication [28].

4 SOCIAL TOUCH

Touch is a significant part of social interaction. As was established in section 3.1, a touch communicates personal and intimate emotions. It establishes intimacy and strengthens the feelings of human connection. Therefore, touch is used to provide emotional support, encouragement, and intimacy [29] and in contrast, also allows you to persuade someone - Midas touch. Midas touch refers to a brief touch that increases a person's willingness to comply [30]. The underlying principle of Midas touch is social touch. Cascio et al. [31] define social touch within two contexts – 1) psychological and 2) physiological effects on a human body. This difference in definition is necessary since it allows a contrast between affective and discriminative touch.

4.1 PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS OF SOCIAL TOUCH

Physiologically, social touch is an effect caused by low-threshold unmyelinated peripheral afferent fibres (C Tactile or CT afferents). These fibres are activated to slow gentle strokes (<10cm/s) [32,33] and at temperatures close to human skin [34]. CT afferents are found only in hairy skin than in glabrous skin of the palm [34] and they affect not only the posterior insular cortex [35] and in some instances, also the primary somatosensory cortex which was previously assumed to be inactive during social touch [36]. CT afferents are deemed suitable for social touch and have been named "social touch systems" [37,38]. The fact that CT afferents are not found in glabrous skin does not make social touch irrelevant in those areas of the body. Actively sending/receiving social touch through glabrous skin is perceived to be pleasant by the user [39]. Furthermore, social touch for providing comfort or compassion towards a loved one has been observed to have variation in signals associated with empathy with respect to EEG [40] and ECG [41].

Psychologically, Cascio et al. explain that partners in exchange of the touch and the intent behind it are also the key elements of social touch. Social touch is always in the context of interpersonal relationships ranging from intimate partners to stark strangers. Naturally, the social touch between intimate partners is powerful. Cascio et al. state that studies regarding touch in romantic relationships support the role of both, neuropeptides, and neural reward systems. Authors of [42] confirm the neural correlation of desire for romantic caress. It explains that, for intimate partners, as the desire to be intimate with the other increases, the neural activity for anticipating a romantic caress from your partner increases. This kind of romantic touch has been observed to positively influence the levels of oxytocin [43], essentially influencing the reward region of the brain. However, an inverse effect was noticed in the case of individuals with autistic traits [44].

4.2 CONTEXT OF SOCIAL TOUCH

While a variety of social touches has been used in psychological interventions, it is not always necessary that that touch arouses pleasant feelings in the receiver. A review paper by Saarinen et al. [45] investigates various contexts in which social touch is applied, ranging from psychosocial factors (facial expressions, acquaintanceship, out-group membership) to situational factors (receiver's situational distress). Figure 2 summarizes the psychosocial and contextual factors which have an

observable effect on the responses to social touch. These factors show that the same caress can be experienced as unpleasant and is not considered to have positive effects of touch to the receiver in the long run. Therefore, to produce a pleasant, secure, and appropriate touch, these factors must be considered while designing the interaction.

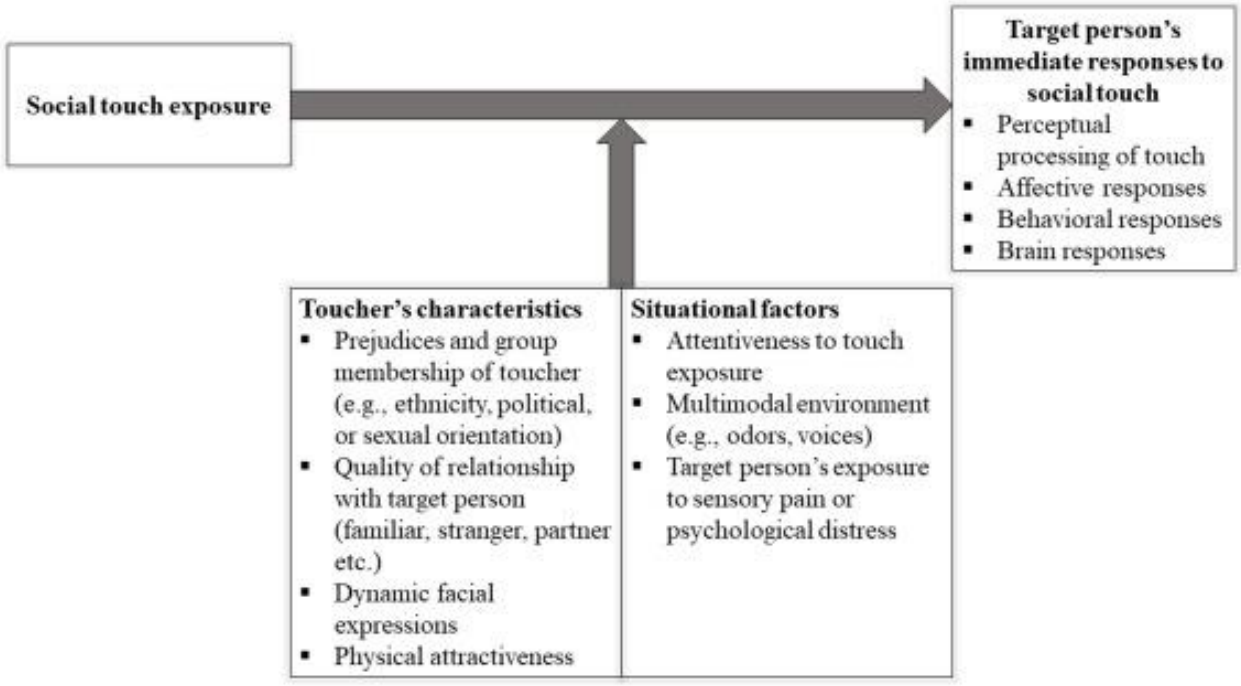


Figure 2. Summary of psychosocial and situational contextual factors modulating responses to social touch [45]

4.3 Social Touch and Empathy

It was established in previous sections that social touch influences the emotions of the target. Since it positively alleviates partners in distress with some exceptions (see section 4.2), could it be said that social touch has a positive effect on empathy? Several studies were conducted where participants in psychosocial stress situations had a positive influence on their friend's or partner's touch [45].

Participants when shown a picture of a deceased close acquaintance experienced the situation more comfortable when holding hands with their partner vs. being alone without touch [46,47]. During the Ebola outbreak, nurses had to always wear PPE while tending to the patients. Despite this limitation, it was observed that nurses were still able to provide meaningful human touch when done with the intention [11]. Another study [48] investigates an analgesic effect due to their partner's touch. The authors found that subjects, after introducing to heat stimuli, reported reduced pain when they were comforted by their partner. Therefore, behavioural evidence suggests that a receiving touch may reduce sensory or even physical pain. When investigating the physiological effects of social touch, similar favourable effects can be seen. For participants under distress, handholding and hugging with a partner or friend reduced blood pressure and lowered their heart rate [49,50].

4.4 WHAT BODY LOCATIONS ARE SUITABLE FOR SOCIAL TOUCH?

Like all types of social interaction, social touch also has tacit rules that must be followed. Suvilheto et al. [51] produced a heatmap of regions of the body that are acceptable to receive social touch with respect to the relationship and gender of the toucher. Figure 3 illustrates the topography of socially acceptable touch regions.

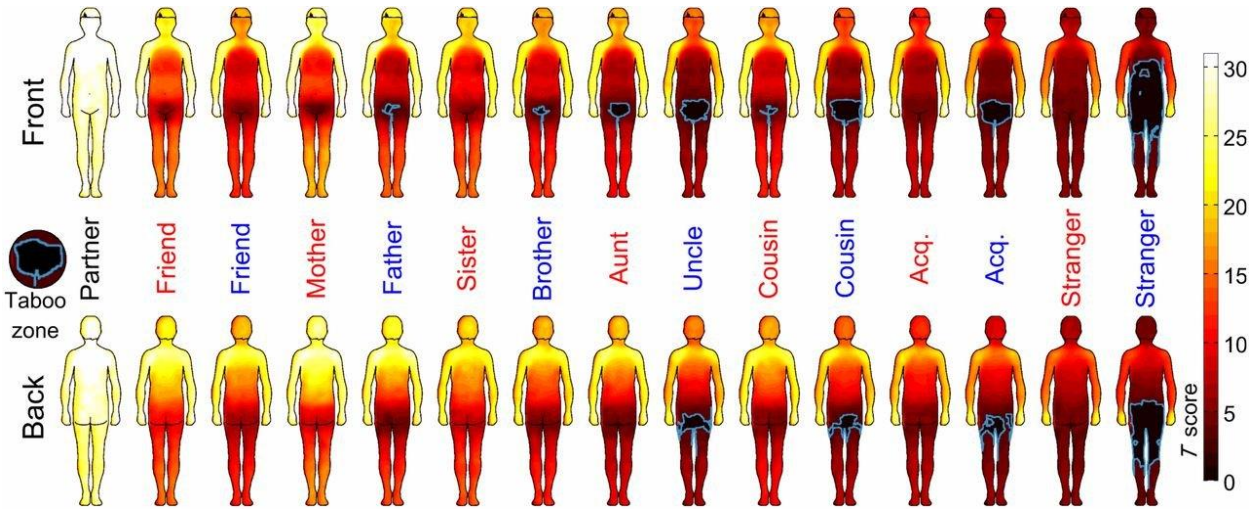


Figure 3. Topography of socially acceptable touch regions [51]

Suvilheto et al. notice a clear distinction between partners touching each other compared to strangers. It is acceptable for romantic partners to touch anywhere around the body. Whereas strangers are strictly limited to touching the other's hands. Another noticeable difference is within genders. Females are allowed to touch a wider area of the body than their male counterparts of the same relation. This is clearly visible in the case of female strangers versus male strangers. Interestingly, hands are the only region that is acceptable for all relationships and genders. Touch, up to the forearm is common across cases of affective relationships such as friends, family, and partners.

4.5 TYPES OF TOUCH

In real life, different touches have different distinct meanings. They can be symbolic, affectionate, or informational. Studies determine social touches emulated through mediated touch (or mediated social touch, MST) have been designed for hugging [52]–[54], kissing [55,56], hand-holding [57], handshaking [58,59], squeezing [60], stroking [61,62], patting [63,64], regular contact [65], or even tickling [66]. These types of touches are often seen in real social touch interaction.

Therefore, MST has the potential to generate any possible type of social touch with respect to any context imaginable. While most of the above-mentioned touches relate to affectionate touch, alternate meanings of each touch can be derived by the participants of the touch themselves. Huisman [67] explains such touch as "symbolic" where the actual social touch does not necessarily have to

match its intended meaning. Instead, the participants of the touch share the context and symbolism of the touch with only each other. Such symbolism can help a wide variety of interactions and can help the designer create a tactile language [68].

5 SOCIAL CONNECTEDNESS

Social connectedness (SC) is a term that encompasses feelings of belonging and closeness. It is defined as a short-term experience of belonging and relatedness, based on social appraisals, and relationship salience [69]. Being social animals, SC is the fundamental aspect of human life. This sense of SC is what allows humans to identify with other humans in society. Social roles like parenthood, an employee working at a company, or even being a child, are examples of shared experiences among many humans. The difficulty of forming a sense of SC translates from childhood to adulthood when the needs were previously unmet [70]. Lee et al. [70] explain that SC encompasses an individual's beliefs and attitude towards other people and relationships. This in turn is linked to the ability to understand others, participate in social activities, and feel related to other people with empathy [71].

5.1 SOCIAL PRESENCE

Social presence (SP), a term coined in 1976, refers to the level of importance of the other person in a mediated communication and how influential are their interpersonal interactions [72]. It is the subjective experience of being present with a person in a virtual environment and having access to their emotions and thoughts [73]. Biocca et al. [73] provide greater insight into SP by defining it in 3 dimensions (see Fig. 4).

1) **Sense of Co-presence** - At the level of perceptual awareness, individuals gain a faint sense of a co-presence, and a basic sense of the other's identity, sentience, and attention.

2) **Psycho-behavioural accessibility** – This dimension is characterized by a deeper sense of psychological involvement, access, and connection to the intentional, cognitive, or affective states of the other.

3) **Mutual co-presence** – In this dimension, SP is the (inter-)subjective judgement of mutual co-presence such as mutual attention, mutual comprehension, shared emotional states, and interdependent behaviour.

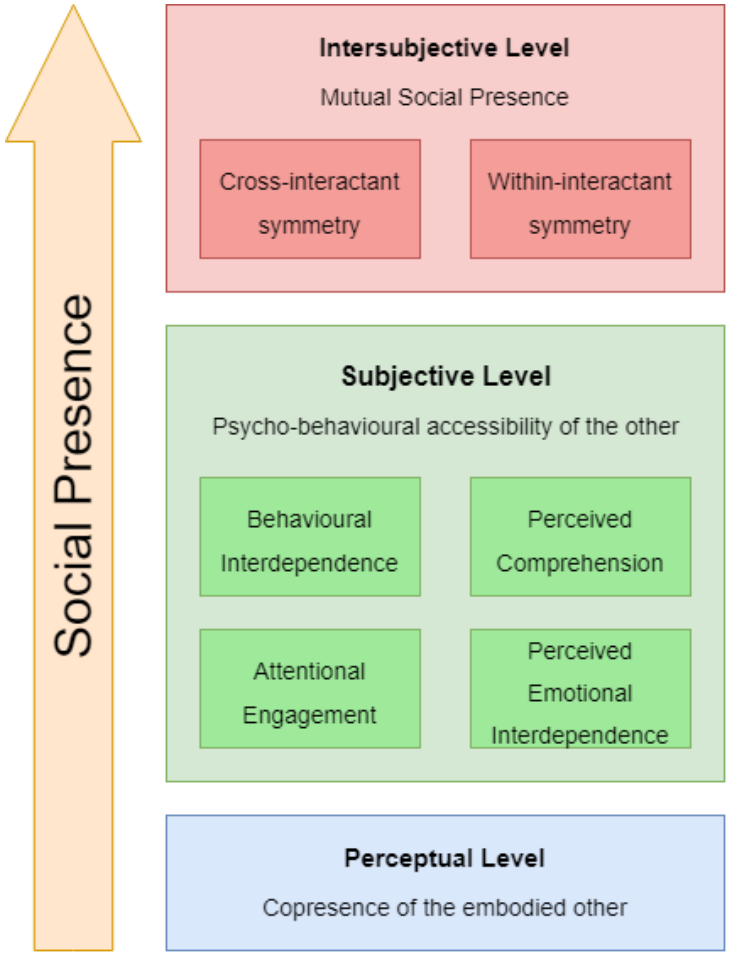


Figure 4. Social presence dimensions [73]

While SP and SC fall under the same branch, they are not the same. In her paper on discussing connectedness, awareness and social presence, Rettie [74] states, *"Social presence is a judgement of the perception of the other participant and/or of the medium, whereas connectedness is an emotional experience, evoked by, but independent of, the other's presence".* Since the dawn of virtual reality for home environments, SP has gained massive academic attraction. Mainly because VR is purported to be a higher level of SP than other technology-mediated communication [75].

5.2 Significance of SP

Studies have shown that SP has a range of positive effects, such as persuasion and attraction [76,77]. A study [78] found that SP was positively associated with trust, enjoyment, and perceived usefulness of a shopping webpage, which led to greater purchase intentions. Lee et al. [76] studied SP in the context of a social robot and measured individuals' co-presence with the robot. Interestingly, they found that SP predicted attraction towards the robot. However, Geen et al. [79] discuss the arousing effects of SP but based on their gathered psychophysiological evidence, it fails to support the hypothesis that this presence increases arousal. On the contrary, their evidence suggests that the presence of others can reduce arousal in individuals under stressful experiences.

6 STATE OF THE ART

This chapter shall narrow down which haptic device or type thereof is best suited to provide a touch stimulus as a wearable sleeve. Finally, various state-of-the-art devices that are currently available in the market shall be discussed. Fig. 1 illustrates two broad categories of haptics – Tactile and Kinaesthetic. Kinaesthetic devices were not deemed suitable since they were bulky and expensive. Therefore, this thesis shall focus on tactile devices.

Among the tactile devices are –

1. **Vibration** – These devices communicate by stimulating vibrations on the user's skin. They are most used in phones, game controllers, and smartwatches. It has relatively low power consumption and is easily controllable. Due to this, vibrotactile devices are commercially popular. The downside is that vibration lacks depth and diversity of sensation.
2. **Spatial change** – These types of devices alter the surface on which the user interacts. They provide a virtual texture to the surface using either array of pins, electrodes, ultrasound, or pneumatics. Examples include refreshable braille displays and ultrahaptics. These devices are often bulky, have a high-power consumption and are not readily available in the market. Therefore, they are usually expensive.
3. **Friction change** – These devices alter the friction based on the interaction between an object and the user. It is done either using electrostatics or ultrasonics. Ultrahaptics [80] is an example of spatial as well as friction change haptics. Like spatial change devices, these also tend to be bulky and consume high power.

Vibrotactile devices use low power, are easily controllable, commercially popular, widely available, and most importantly, are less bulky [81], therefore they shall be suitable for this study. But even within vibrotactile haptics, there are different types of vibrations (Fig. 1).

6.1 VIBROTACTILE TECHNOLOGIES

6.1.1 Eccentric rotating mass (ERM)

The principle of this motor is an eccentrically rotating mass around an axis which in turn generates vibration. The benefit of ERM motor is that this technology has been used for a long time and therefore has matured. It is used in mobile devices, game controllers, and watches, for providing a tactile notification or haptic feedback. Since the technology matured, these are widely available in various specifications and designs at a low cost. The problem with the ERM motor is that it consumes a lot of power to move the mass, and therefore has a slow response (start and stop) time and the frequency of vibration depend on the frequency of input power [82].

Generally, ERM motors are quite bulky (Fig. 5) and therefore not a good option for haptic wearables. Instead using coin version of ERM motors are preferred for wearables (Fig. 6) since they are small, lightweight, do not need a driver, and robust. The downside is that they are not as powerful as the bigger versions [83].

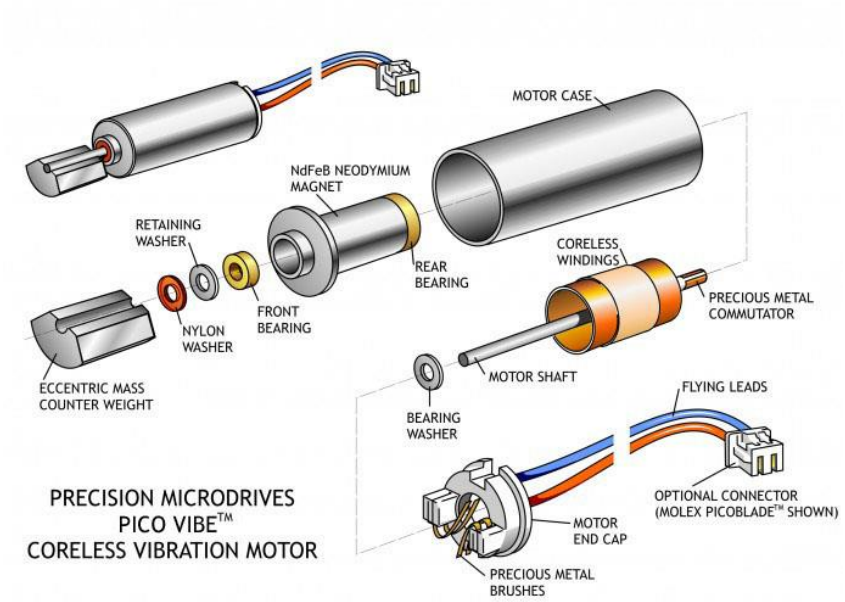
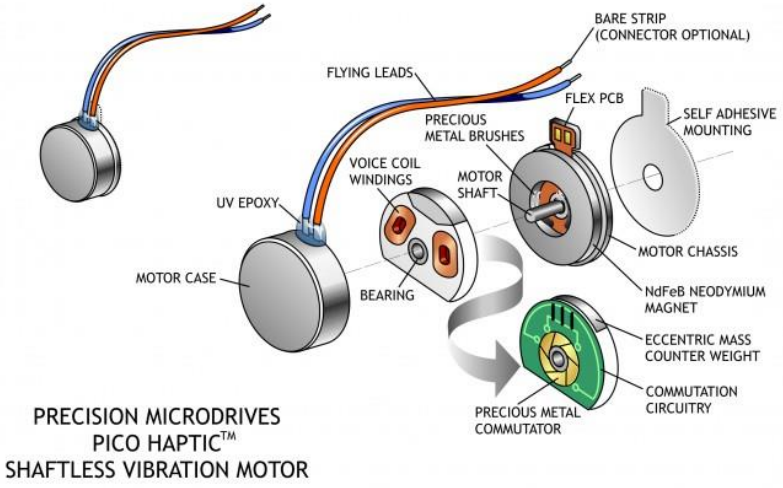


Figure 5. ERM motor [84]



HYPERLINK "https://www.precisionmicrodrives.com/eccentric-rotating-mass-vibration-motors-erms"

Figure 6. Coin ERM motor [83]

6.1.2 Linear resonant actuator (LRA)

This device rapidly moves a mass back and forth across a linear axis. It is a simple spring-mass mechanism activated by a voice coil. The mass coupled with a magnet moves based on a defined resonating frequency of the device. LRAs are gaining popularity since they are reliable, responsive and consume low power [85]. They are also widely available but more expensive than ERM. The disadvantage of using LRA is that the resonant frequency varies for each and therefore any frequency outside the resonant frequency will result in reduced vibration amplitude.

While LRAs seem objectively better than ERMs, they do have one major limitation. ERMs can run with or without an additional driver but LRAs always require a driver to run the actuator at its resonant frequency [85]. Depending on the size of the driver, the actuator can become bulky.

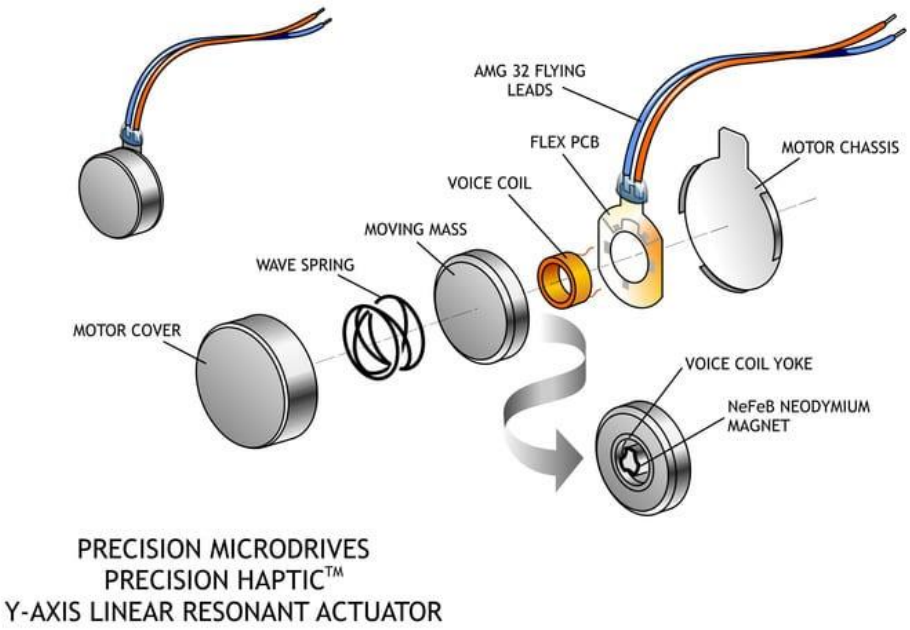


Figure 7. Coin LRA [85]

6.1.3 Voice coil motor (VCM)

Voice coil motors contain a coil around a permanent magnet. Depending on the type of the motor, either the magnet can move linearly from a fixed coil, or the coil can move linearly from a fixed magnet. This simplistic design makes allows the motor to have a smaller form factor, a constant force, and high accelerations [86].

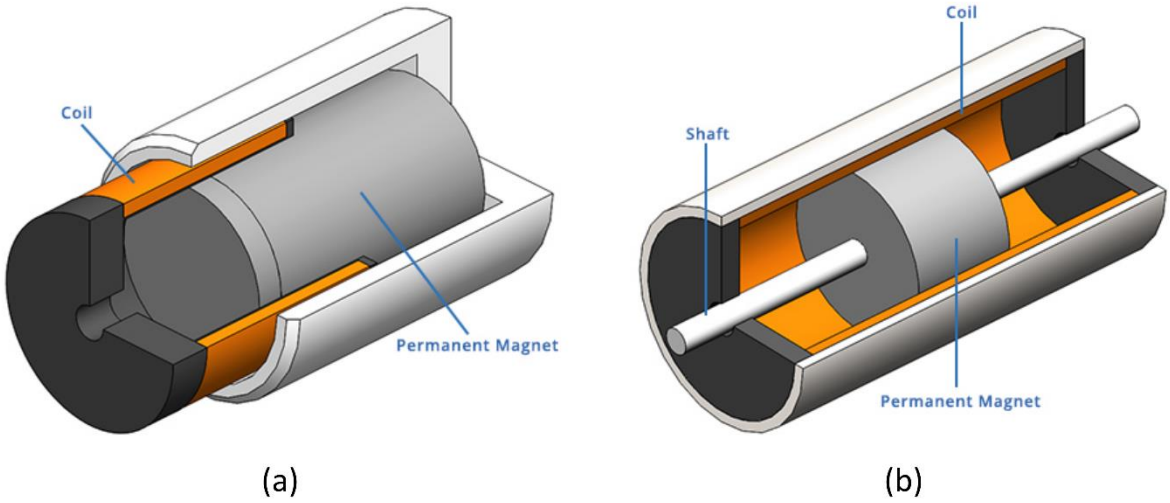


Figure 8. Voice coin motor with (a) Moving coil (b) Moving magnet [86]

6.1.4 Piezoelectric transducers (PZT)

Piezoelectric transducers generate vibration using piezoelectric materials mounted on a suspended beam [82]. An electric signal causes the beam to compress and stretch rapidly causing vibration. The benefits of PZT include smaller size, low-power consumption, high precision, quick response, and non-magnetic. But they are limited by their higher operating voltage and sensitivity to electrical overdrive. PZTs are used in a wide range of applications like audio systems, medical technology, or optics.

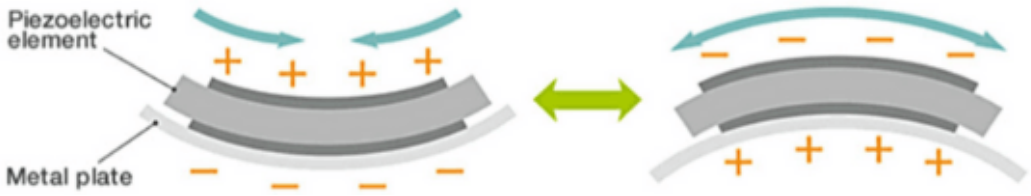


Figure 9. Piezoelectric motor [82]

6.1.5 Solenoid actuator

Solenoid actuators are also called impact actuators [82]. A solenoid generates an electromagnetic field around an armature. When it is energized, the armature is pulled and pushed into a cavity. It is a bigger version of LRA with a broader frequency response range. They are also used in a wide range of devices including gaming, virtual buttons, phones, and automobile dashboards. The use case of this actuator is based on the impact sense – representing a sudden impact. Therefore, all subsequent impacts have lower force [87]. As mentioned before, solenoid actuators have a wide range of frequency responses and higher forces due to impact. Naturally, this device consumes high power and is bulkier. Furthermore, it also requires custom drivers which makes it expensive.

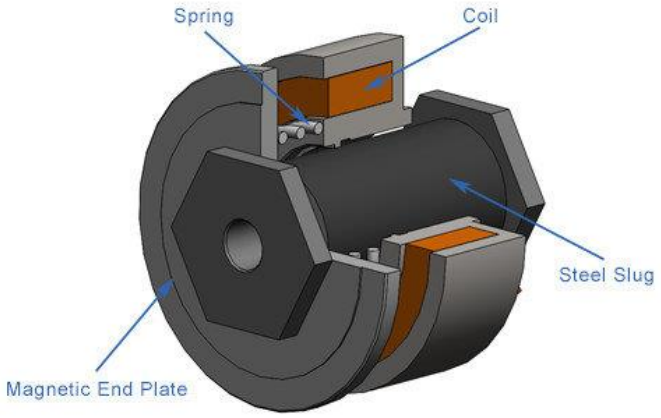


Figure 10. Solenoid motor [87]

6.2 STATE-OF-THE-ART VIBROTACTILE SLEEVES

Due to their advantages, coin ERMs were chosen to be a part of this study. Therefore, the following devices use coin ERMs.

6.2.1 The TaSST device

Figure 11. TaSST arm sleeve [62]

TaSST (Tactile Sleeve for Social Touch) is a vibrotactile arm sleeve made for communicating 6 different types of touch remotely between two people. The creators of TaSST [62] studied this device – 1) to

observe how different vibrotactile patterns could be perceived as different types of touch, and 2) to assess to what extent the prototype could be used to communicate these touches at a distance. These touches are simple (poking, hitting), protracted (pressing, squeezing), and dynamic (rubbing, stroking). It has two-way communication enabled; therefore, it can send and receive touch. The input layer consists of a 4x3 grid of 40x40 mm lycra pads filled with conductive wool. Below the input layer, the output layer consists of coin ERMs in a 4x3 grid. The rotation speed of the motors is determined by the force applied to the input layer. The authors indicate that dynamic touches were hard for the participants to perceive and imitate. Whereas simple and protracted touches were understandable for the users.

6.2.2 bHaptics Tactosy

Figure 12. bHaptics Tactosy [88]

bHaptics Tactosy is a commercially available haptic sleeve for arms. It is used as a pair of sleeves where each pair has 6 vibration motors laid in a 3x2 layout. The main use case of this device is for gaming, audio-based haptics, and personal entertainment. Therefore, the motors respond to interaction in games, convert music to vibration and serve as a notification provider. In a study related to body-based haptic feedback, the authors used the sleeves and a haptic vest to investigate the effect of body-based haptic feedback on a player's sense of presence and overall experience during VR gaming [89]. However, they could not find significant differences in the player experience and sense of presence.

6.2.3 Elitac whisperer haptic sleeve

Figure 13. Elitac whisperer haptic sleeve [90]

Elitac emotion sleeve is a custom-made vibrotactile sleeve that was created to aid visually impaired people to feel facial expressions [90,91]. The sleeve conveys emotions through various patterns of vibrations. It acts as a tool for visually impaired people to see other person's facial expressions with the help of smart glasses, emotion recognition software and the vibrotactile sleeve. The software, through the smart glass, can see and recognize 6 types of emotions (happiness, sadness, disgust, fear, surprise, anger) and their intensity as well. It contains 16 vibration motors that can create 24 distinct patterns combining taps and strokes at various points in the lower arm.

6.2.4 Bespoke vibrotactile sleeve

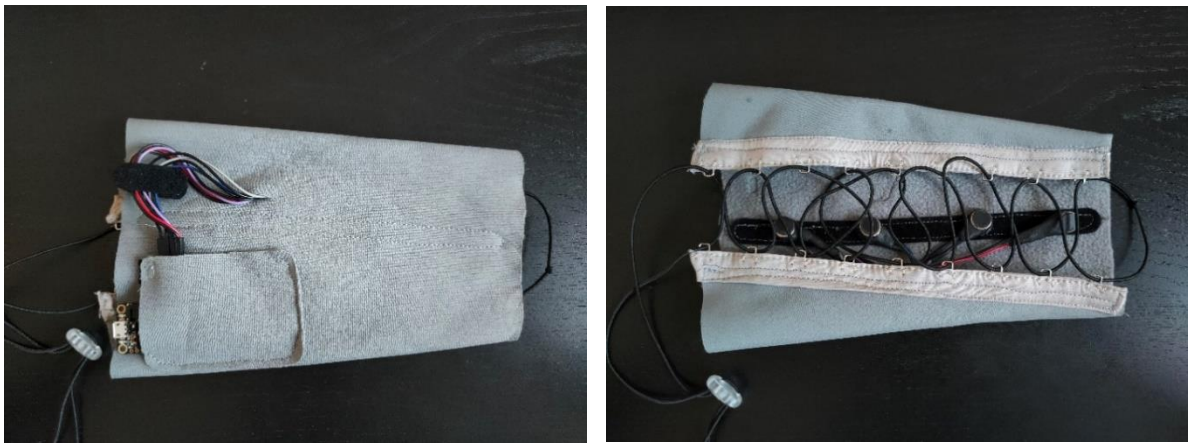


Figure 14. Vibrotactile sleeve

This vibrotactile sleeve is a prototype that was created at the University of Twente specifically for haptic studies. It contains four adjustable coin ERM motors. These motors can be placed anywhere along the length of the sleeve. The motors are controlled via an ESP32 programmable board and therefore, the sleeve can emulate a stroke or a pat. The sleeve is very lightweight, flexible, easily programmable, and succinct, thereby making it very suitable for this study.

6.3 TESTED HAPTICS

This section was considered significant to include since the devices mentioned here were once considered within the scope of this study but were later deemed unsuitable. Therefore, this section serves as a guideline on what devices to avoid for such a study in the future. Three other devices were also explored, despite the limit to using vibrotactile haptics

6.3.1 Ultraleap STRATOS

Ultraleap STRATOS explore is an ultrasonic haptic device. It has 256 ultrasonic transducers in a 16x16 grid [80]. The device tracks the user's hand with a LEAP motion controller and activates the transducers together to form a 3D object sensation at around 15-20cm above the device. It was controlled by an interface which contained specific presets. While it was successful in stimulating the palms but failed in stimulating the forearm.

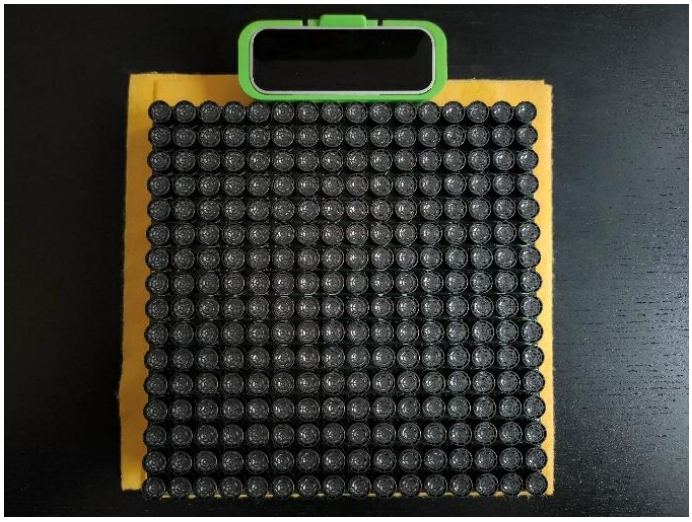


Figure 15. Ultraleap STRATOS explore development kit [80]

6.3.2 Elitac-Manus sleeve

Figure 16. Elitac-Manus haptic glove by TNO (front and back)

This glove was developed by TNO. It consists of a Manus VR glove for hand tracking fitted with Elitac's vibration motors for haptic feedback. There are 14 vibration motors, 2 per finger, 2 on the palm and 2 behind the palm. It was made for TNO's Social XR project [92]. The glove was used to emulate a handshake, fist bump and high five. Since it cannot be used on a forearm, this was glove was unsuitable.

6.3.3 McKibben actuator

Figure 17. McKibben muscle [93]

McKibben actuators also called pneumatic artificial muscles, extend or contract when filled with pressurized air. The device was a sleeve that consisted of 3 of these actuators that were activated with a control device. It produced a light squeezing sensation. However, the entire setup was bulky with tubes and valves and had a very loud air pressurizer which required earmuffs to operate.

6.4 CONCLUSION

State of the art aims at answering the question “What is the state of the art in vibrotactile sleeves?”. Here, various devices were explored both tactile and kinaesthetic and provided information on each. Kinaesthetic was considered unsuitable for this study and therefore tactile technologies were considered, specifically vibrotactile. Various vibrotactile technologies were studied based on their mechanism, use case, advantages, and disadvantages. Among these, coin ERM motors seem to be suitable for this study since they are small, no driver needed, lightweight, low cost, mature technology, robust, and are suited for wearables. Therefore, four vibrotactile devices that use coin ERMs were studied – TaSST, Elitac Emotion sleeve, bHaptics Tactosy, and a bespoke vibrotactile sleeve. The bespoke vibrotactile sleeve from the University of Twente was chosen to be a part of this study since it is very flexible, customizable, and lightweight. Other devices that did not fit the scope of this study are mentioned in section 6.3. Appendix A summarizes all the details of the studied devices.

7 SETUP DESIGN

Since the study is explorative, the setup should be a low-fidelity prototype which can be improved depending on the results. The setup and interaction were built with a specific set of criteria. They are as follows:

7.1 DESIGNING THE SETUP

- Corner table conversation – The setup should be such that people should feel as if they are sitting closely. A corner table setup would allow that since it would make the users sit much closer to each other than on opposite sides of a table.
- Video call software – The video calling software should be easy to implement.
- Life-size view of the other – In order to bring full immersion [94], it would be best to replicate the real size of the person the users are talking to. Therefore, having a large screen, preferably a TV should show life-size view.
- Maintain eye contact – Eye contact plays an important role in maintaining the attention of the users [95]. Since the setup has a life-size view of the other, it should also make sure that the people maintain eye contact.
- Background continuation – To seem as if the users are in the same space, the backgrounds should look continuous. It should be as if they are looking through a glass.
- Directional sound – In regular face-to-face conversation, one expects the sound from the other's mouth. Failure to do so could cause cognitive dissonance. Therefore, to maintain immersion, the sound should seem as if it is emerging from the mouth of the other seen through TV.

To create a low fidelity setup, decisions were taken accordingly. Since any table with edges would have corners, they would be suitable for a corner table conversation. MS Teams was used for video calls since it is widely used, easy to implement, and has features that could potentially help with background continuation. A 46-inch TV with a stand was used in portrait mode to show the life-size view of the other person. Various methods were used to mimic eye contact ranging from gaze-correction software to fixed stands. Finally, a camera-gooseneck attached from the top of the TV worked well since it was low fidelity and did not cover the image of the other person. To solve the issue of background continuation, 2 regular office rooms were used which had white backgrounds. Furthermore, window screens in both rooms were drawn and they were only lit with the overhead lights. To create sound from the mouth, 2 speakers were installed at the back of the TV. These speakers were both pointed to the user which created a stereophonic sound and thus achieved the required effect. To summarize:

- Corner table – A regular table with edges
- Video call software – MS Teams
- Life-size view – 46-inch portrait TV with a TV stand
- Eye contact – Camera with gooseneck hung from the top of TV at eye-level

- Background continuation – 2 identical-looking office spaces with white background
- Directional sound – 2 angled speakers behind the TV

7.2 DESIGNING THE INTERACTION

- A visible limb for interaction – A limb, specifically an arm, should be visible to the user for them to interact. That limb should send a signal to the vibrotactile sleeve.
- Patting/holding touch – Patting or holding someone's arm is a good way to comfort someone when they are distressed (see section 4.5) and is easily programmable.
- Touch should be out of view – It is a well-known phenomenon that the brain fills in missing information when something is not visible [96]. Therefore, when the user leans to touch the limb, the interaction should be out of view the camera. Doing so would make the recipient of touch feel the vibration and assume that they are being touched without seeing the mannequin arm.

For the interaction, a mannequin arm would be suitable to mimic an arm. The arm would be fitted with force-sensitive resistors to sense whether the user is holding or patting and with what intensity. When the user pats, the vibrotactile sleeve begins to vibrate. The mannequin arm could be placed along the edge of the table near the TV so that it stays out of view but is easy for the user to touch. To summarize:

- Visible limb – Mannequin arm
- Patting/Holding touch – Easily programmable
- Out-of-view touch – Place arm near edge of table

Based on these criteria and decisions, figure 18 shows the final setup prepared for this study.

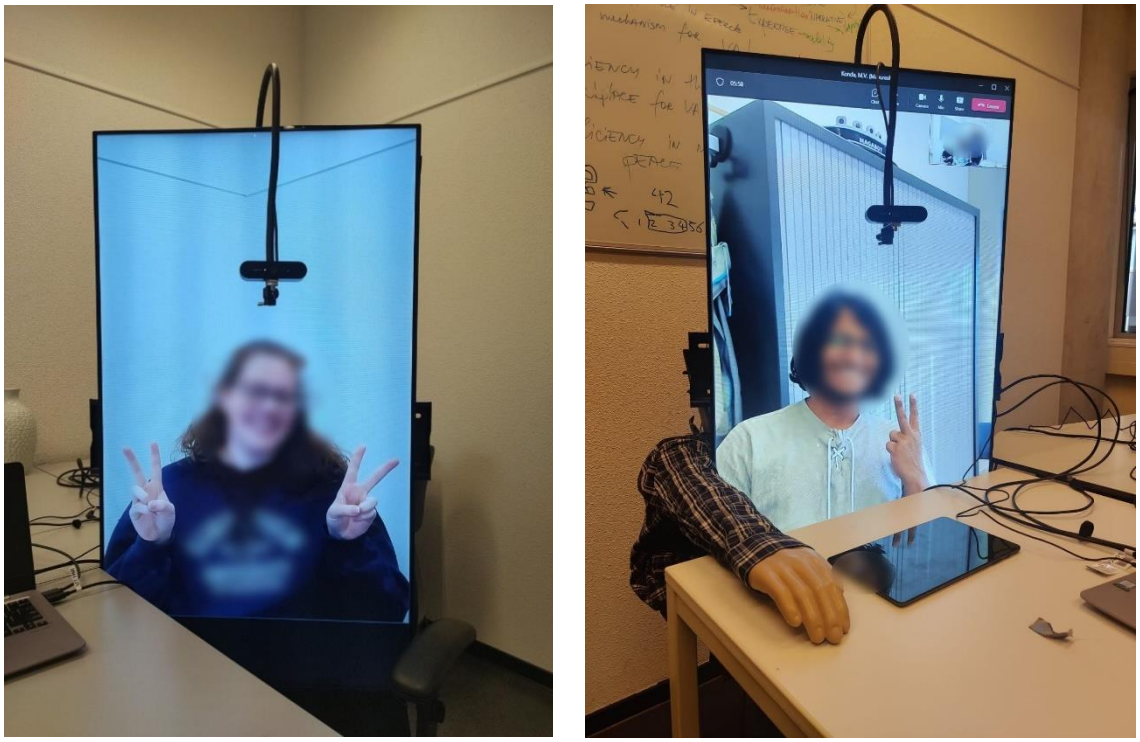


Figure 18. Final setup

Appendix B contains various other designs explored during the finalization of the design.

8 METHODOLOGY

8.1 PARTICIPANTS

A sample size calculation with the following parameters, a confidence interval of 95%, a margin of error of 15%, and a large population resulted in a sample of 43 participants [97]. To have full pairs, a total of 44 participants or 22 pairs. The pair of participants should be between the age of 18 to 65, should have experience with MS Teams, proficient in English and should share an affective relationship – family, friends, or partner. Furthermore, the participants shall be included such that there is a balanced distribution of male and female participants. Participants with vision/auditory problems or with attention disorders shall not be included.

8.2 STIMULI

It has been seen that video stimuli have a higher affinity to inducing sadness in individuals [98]. Five videos rated for eliciting compassion have been selected from a validated database [99,100]. These videos are 2-5 min movie clips that have been validated to elicit feelings of compassion. Compassion was chosen because it is the emotional response to empathy which in turn has a stronger effect on presence [101]. These videos are sad in nature and contain events of death, grief and/or hardship but do not contain gory elements. The videos and their description are in the table below.

Title	Year	Description	Link
Armageddon	1998	The protagonist volunteers to sacrifice himself to destroy an asteroid hurtling towards Earth. He talks to his daughter over a video call and apologizes that he cannot come home.	https://youtu.be/2H0pnL03vB0
Pursuit of Happyness	2006	The protagonist and his kid struggle to find a place to stay for the night after they are evicted. The kid goes to sleep but the protagonist tries to block anyone trying to enter the toilet so that his kid can sleep properly.	https://youtu.be/S4aMoMccBlQ
Lost	2004	In a sinking submarine, one of the protagonists gets stuck. The other tries to save her but fails. So, he chooses to go down with her.	https://youtu.be/9PVJJsN9GW8?t=137
The Champ	1979	In the aftermath of a boxing match, the protagonist lies dead in a room. His child starts crying over the loss followed by everyone else in the room.	https://youtu.be/WuH__IGnovA
My Girl	1991	A funeral scene of a boy who was a very close friend of the protagonist. She cannot bear the loss and runs away from the funeral.	https://youtu.be/p4li1iuctzQ

Table 1. List of emotion-eliciting videos [99]

8.3 PROCEDURE

The experiment will test 2 conditions:

- Control - Regular video call (MS Teams) displayed on the portrait TV.
- Experiment – Video call with a haptic device on one of the participants' forearms.

Condition 1 is a control condition. In condition 2, the participants will be introduced to the haptic setup. One of the participants shall be the sender and the other will be the receiver of the touch. Both conditions will be tested with a large portrait TV to provide a human-size image and will be in 2 identical spaces. Doing so aims to ensure realism as to sitting in the same space. The vibration sleeve will be placed only in the receiver's room and the sender will be able to send the touch using a pressure sensor setup on a mannequin arm.

8.3.1 Condition 1: Regular video call

A 46-inch TV screen was mounted vertically on a stand and placed over a chair, adjacent to the participant in the room. The video call was done using MS Teams. Both participants saw each other through the screen. A webcam (with microphone) was attached to the screen with a gooseneck such that, the camera placement seemed just above the eyes of the participant on screen. Doing so allowed the participants to maintain eye contact and synchronized the backgrounds on the screen to the background of the room they are in. Speakers were placed behind the screen to give a spatial audio experience. Self-view in Teams will be disabled to avoid any distractions. Finally, the title bar and teams menu bar were moved out of the screen such that, participants can completely see each other on the screen without any other interruptions.

Figure 19. Setup without haptics

8.3.2 Condition 2: Video call with haptic setup

The setup is identical to the setup in condition 1, except for the addition of the haptic setup. The haptic setup consists of a vibrotactile sleeve (Fig. 21), and a mannequin arm fitted with pressure sensors (Fig. 22). The sleeve would be worn by participant B on their right arm and participant A would interact with the mannequin arm. In different instances, participant A will be indicated to touch participant B by pressing on the mannequin arm. The indication will be in the form of a subtle knock on the door. Doing so will vibrate the sleeve on participant B's arm.

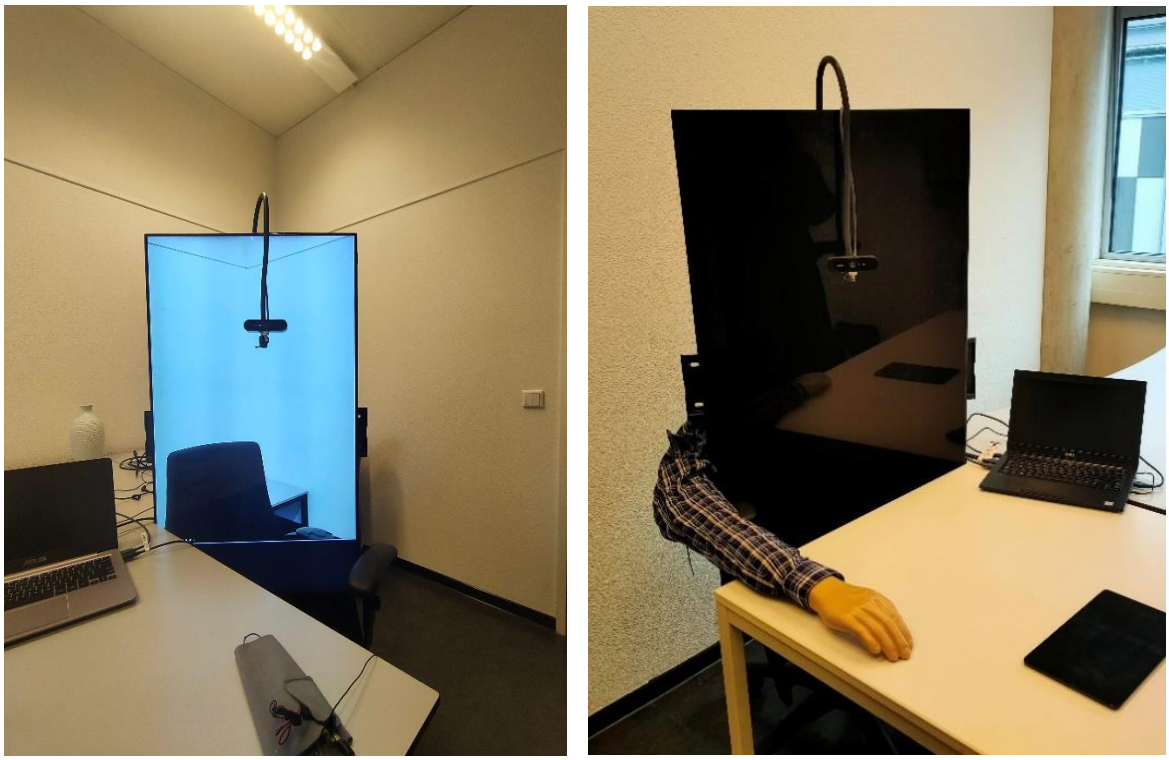


Figure 20. Setup with vibrotactile sleeve (left) and mannequin arm (right)

Figure 21. Vibration sleeve

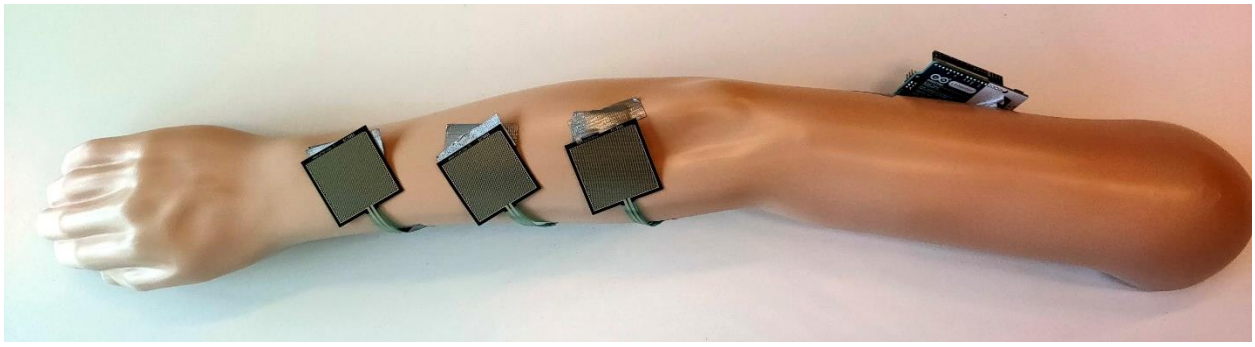


Figure 22. Mannequin arm with pressure sensors

8.4 QUESTIONNAIRE

In this study, we will use an evaluation methodology based on multiple existing questionnaires adapted to fit the scope of this experiment. See appendix C for the full questionnaire.

8.4.1 Holistic social presence questionnaire (HSPQ)

HSPQ presents a holistic method of measuring the quality of experience of mediated social presence [102]. For this study 10 items shall be included from HSPQ, viz. the social presence scale which includes sensory, emotional, cognitive, behavioural, and reasoning from the perspective of self and partner.

8.4.2 Networked minds measure of social presence (NMQ)

Authors of [73] defined the psycho-behavioural accessibility of a person in a virtual environment. The same authors developed a measure of social presence [103]. For this study, the psychological involvement scale shall be used which includes 12 items, viz. empathy scale and mutual understanding scale.

8.4.3 Discrete Emotions Questionnaire (DEQ)

DEQ measures emotion in 8 discrete emotions rather than broad dimensions of affect [104]. For this study, the questionnaire is adapted to use items that relate to empathy, viz. sadness, anxiety, fear, and desire. It includes 11 items.

8.4.4 Short User Experience Questionnaire (UEQ-S)

This questionnaire measures the experience of the user based on its attractiveness, pragmatic quality, and hedonic quality [105]. This study uses this questionnaire merely for exploratory purposes, to see how the participant perceives the system in its current state. As such, only the short version of UEQ is utilized which contains 8 items.

8.4.5 Demographics

Demographics (age and gender) information is collected to determine correlations between the responses and the sample used.

There will be one questionnaire at the start and end of the experiment. The entry questionnaire is the DEQ and consists of 11 items in total. The exit questionnaire is a combination of all the ones mentioned above. Therefore, it consists of 43 items. Nothing apart from the questionnaire, such as the conversation or the meeting is recorded.

8.5 TIMELINE OF EVENTS

On the day of the experiment, the two participants will be placed in different rooms and introduced to the system that they will use to interact with the other participant. They will then fill out a questionnaire about their current emotional state. If the participants are in condition 2, they will be introduced to the haptic setup. They will be given time to try out the system to eliminate the novelty effect.

Once they are ready, they will be shown one of the five emotion-inducing videos from Table 1, selected at random. Once the video ends, the participants will be asked to talk about personal events that might have been emotional for them. To stimulate conversation between them prompts will be provided regarding place, time, etc (see appendix D). Participants are free to talk about anything else they would naturally discuss with each other. They can finish the conversation at any moment, with a limit of 15 min. For participants in condition 2, the sender shall receive a notification to touch the mannequin arm, thereby sending a touch to the other participant.

After the conversation, both participants will be asked to complete the evaluation questionnaire in digital format.

9 RESULTS

9.1 DEMOGRAPHICS

This experiment consisted of 22 pairs of participants (N=44) divided into 11 pairs per condition. All participants were either close friends, family, or partners, with the majority being friends. The mean age of participants was 23.93 ± 3.32. There were 7 male-male pairs, 3 female-female pairs and 12 male-female pairs resulting in 26 males (59.1%) and 18 females (40.9%).

9.2 SOCIAL PRESENCE

HSPQ: A 7-point Likert scale (1=Strongly disagree to 7=strongly agree) was used for this questionnaire. No significant differences were found in both conditions on the scores of the HSPQ questionnaire. However, the internal consistency of all the subscales was found to be above 0.7.

Scales	No haptics	Haptics	Cronbach's alpha	p-value
Immediacy	5.50 ± 1.55	5.50 ± 1.26	0.807	0.735
Intimacy	6.00 ± 0.83	6.00 ± 0.79	0.726	0.839
Naturalness	6.00 ± 1.15	6.00 ± 1.05	0.772	0.713
Behaviour	5.75 ± 0.99	5.50 ± 1.02	0.707	0.365
Reasoning	5.50 ± 1.38	6.00 ± 1.34	0.760	0.173
Total	5.75 ± 1.38	5.80 ± 1.09	0.811	0.810

Note: Data was right-skewed; using median values.

Table 2. HSPQ scores

NMQ: This questionnaire also used a 7-point Likert scale like in HSPQ. 2 questions in the empathy scale were corrected for reverse coding. No significant differences were found between the conditions.

Scales	No haptics	Haptics	Cronbach's alpha	p-value
Empathy	5.25 ± 1.15	5.31 ± 1.55	0.923	0.624
Mutual Understanding	6.00 ± 0.84	6.02 ± 0.95	0.958	0.723
Total	5.63 ± 0.99	5.67 ± 1.24	0.942	0.847

Note: Data was right-skewed; using median values.

Table 3. NMQ scores

9.3 EMOTION STATE

Emotion states were measured before watching the video (entry) and after finishing the conversation task (exit). A 7-point Likert scale was used (*not at all* to *an extreme amount*). The responses were recoded from 0 to 6 since "1" corresponds to *not at all*. Cronbach alpha for the entry and exit emotion questionnaire scored 0.899 and 0.835, respectively.

A basic comparison between entry and exit questionnaires showed that sadness and grief are the two main emotions that are seen after the task. This was anticipated since the videos watched by the participants contain elements of death, hardships, or grief and therefore elicit feelings of sadness or grief. However, across the two conditions, haptics has reduced scores of both sadness and grief.

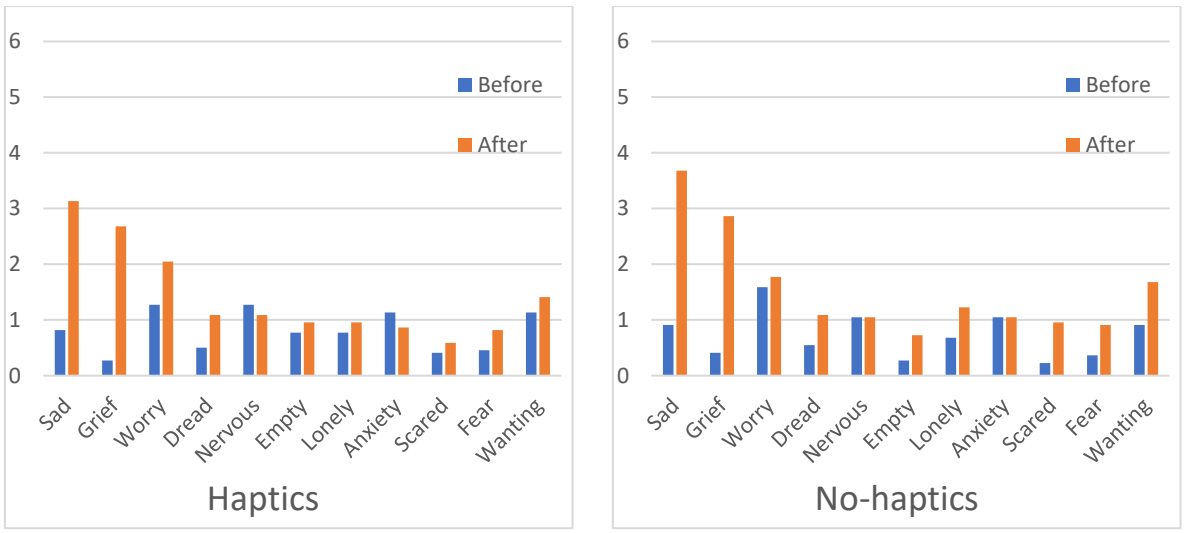


Figure 23. Before-after emotion comparison

To further analyse the difference in emotions, a difference in differences model [106] was applied to measure the jump in emotions before and after the experiment for each condition. Fig. 2 shows the jump in emotions between haptic and no-haptic conditions along with the difference in jumps. Upon measuring the jump, it was seen that sadness had a reduced score of 0.5 but grief had no difference. However, participants also felt less scared and wanted in the haptic condition but felt more worried.

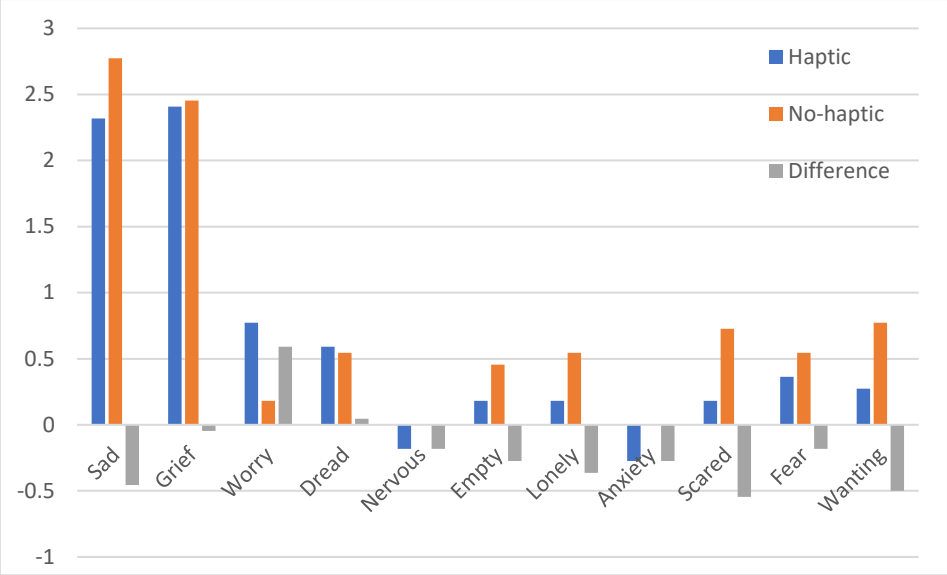


Figure 24. Jump in emotions between conditions

9.4 User Experience Questionnaire

The analysis of UEQ was done as per the instructions of its authors. Pragmatic quality refers to the practicality of the setup and hedonic quality refers to the aesthetic features of the setup. Table 1 shows the pragmatic, hedonic, and overall scores of the setups. The authors interpret scores above 0.8 as a positive evaluation. Also, scores outside the range of -2 to +2 are considered highly unlikely Therefore, it is evident that both setups received quite a positive evaluation.

Scales	Haptic	No-haptic
Pragmatic quality	1.59	1.75
Hedonic quality	1.74	0.91
Overall	1.67	1.33

Table 4. Setup scores

Furthermore, the authors also provide a benchmark to compare the setup with the results of other (468 at the time of making this thesis [107]) studies. However, the benchmark data has been extrapolated from the full UEQ since short UEQ is relatively new (published in 2017). Therefore, the benchmark provides a first rough estimation. Fig. 2 and 3 represent the benchmark for haptic and no-haptic setups, respectively. Both setups have received quite a positive benchmark score, with the only difference in the hedonic quality between haptic and no-haptic setups. The haptic setup scored 1.74 whereas the no-haptic setup scored 0.91. Overall, the no-haptic setup received a *Good* benchmark whereas the haptic setup was benchmarked as *Excellent*. Appendix E contains the individual item scores for both setups.

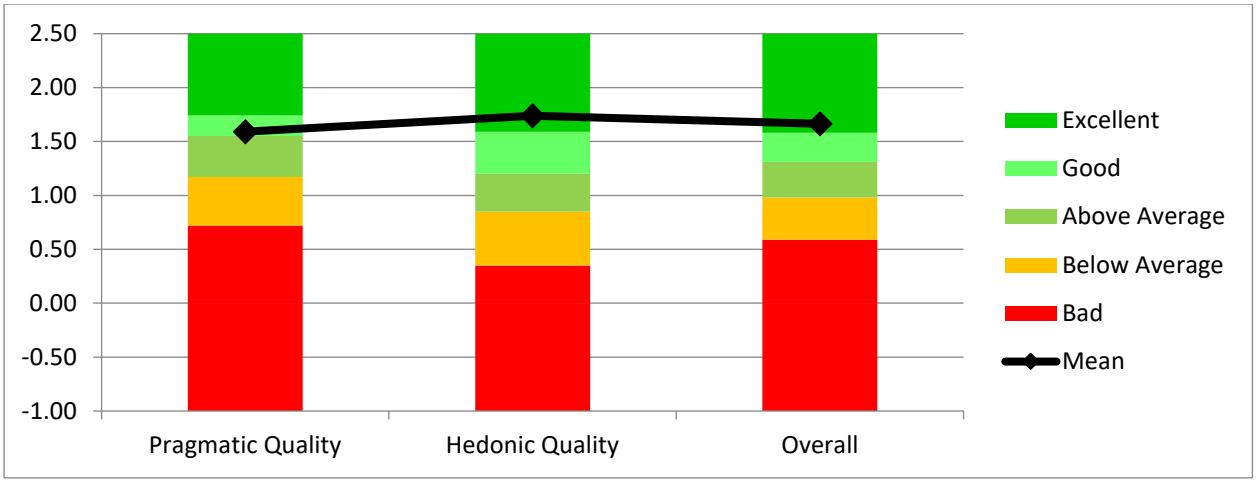


Figure 25. Haptic setup benchmark

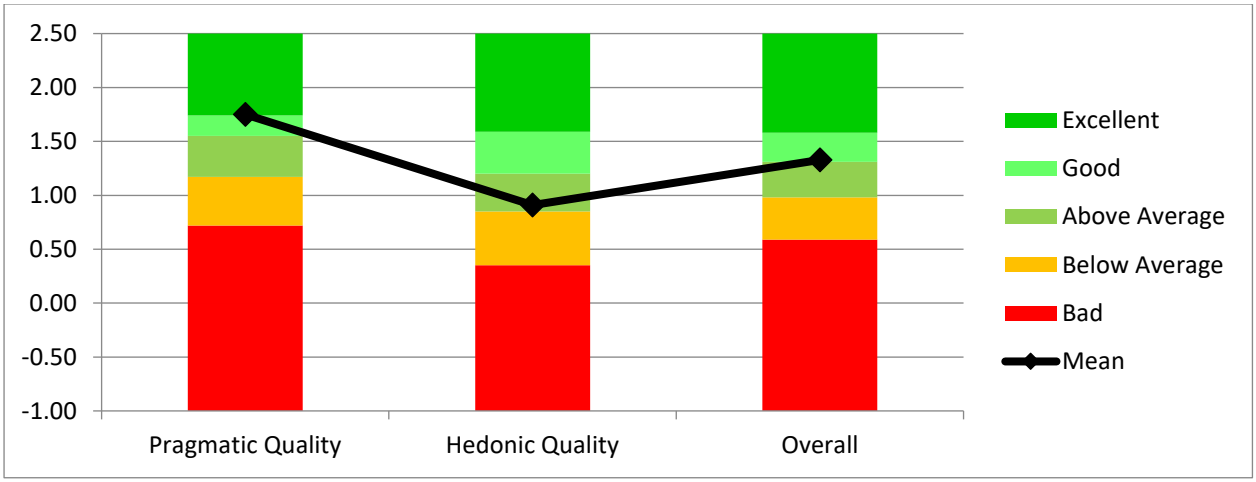


Figure 26. No-haptic setup benchmark

10 DISCUSSION

From Oct 2021 to May 2022, an explorative study was conducted. The study was inspired by social distancing protocol in the COVID-19 pandemic which meant people were not allowed to be near each other. Therefore, people in affective relationships, such as friends, family, or romantic partners were not allowed to socially touch each other unless they were in the same household. However, similar situations arise in people in long-distance relationships, under hospitalization, isolation, and quarantine. Mediated social touch could help in such a scenario, allowing people to touch each other remotely via the internet.

10.1 RESULTS

10.1.1 Social Presence results

For this study, two measures of social presence were used: Networked Minds Questionnaire [108], and Holistic Social Presence Questionnaire [109]. According to the followed methodology, social presence results yielded inconclusive results. Participants did not perceive a significant difference in social presence between conditions in either measure. However, both conditions received a score greater than 5. This positive score could be the effect of using a life-size view of the partner [110]–[112] which is present in both conditions. A similar study by Alvarez et al. reached similar inconclusivity for social presence [94]. This could point towards novelty effect as another main argument for no significant difference between conditions. The setup (TV or sleeve/mannequin) could possibly draw the participant's attention from the conversation and therefore break the feeling of non-mediation necessary for social presence [113].

10.1.2 Emotion state results

In order to see if the participants were successful in comforting each other during the conversation task, the emotion state was measured. A basic before-after comparison of each condition revealed that the participants felt feelings of sadness, grief, and worry more than any other emotion. Across the two conditions, haptics has reduced scores of both sadness and grief (Fig. 23 Haptics) when compared to no-haptic (Fig. 23 No-haptics). This was an anticipated difference since with haptics, participants could communicate via touch which is better suited to comfort someone in distress [29,45].

Due to a limitation in methodology, a video*conversation effect was measured. Section 12 discusses it in detail. To counteract this effect, the difference in differences model was used. Figure 24 shows the jump in emotions before and after the experiment. It was seen that participants felt less sad, scared, and wanting in the haptic condition than in the no-haptic condition. This can be attributed to the comforting touch action present only in the haptic condition. However, the feelings of worry among participants in the haptic condition were higher than in the no-haptic condition. Participants apparently felt more worried. This was unexpected. Another unexpected effect was grief. Differences in grief were expected to be higher but it turned out to be similar in both conditions.

10.1.3 User Experience results

User Experience Questionnaire was included to perceive how the user feels about the setup. Table 4 shows the scores for the pragmatic and hedonic quality of the setup. It was seen that for the setup that included the mannequin arm and haptic sleeve, the overall score was 1.67 whereas, for the no-haptic setup, it was 1.33. This was an unexpected outcome. Originally, it was anticipated that users might feel that the sleeve was distracting and therefore, disturbing to the experience. Haptic sleeves are not a household item, therefore it was reasonable to assume that when participants interacted with it they might get distracted by the vibrations. However, the users favoured the haptic setup.

On a closer investigation, it can be seen that the pragmatic quality of the haptic setup scored lesser than the no-haptic setup (haptic=1.59, no-haptic=1.75), but the difference in hedonic quality scores of the haptic and no-haptic setup is quite huge (haptic=1.74, no-haptic=0.91). Figures 25 and 26, show that the pragmatic quality of haptic setup was benchmarked as *Good* but that of no-haptic setup was *Excellent*. A potential reason could be that participants found the haptic system too complex to be practical for daily life since a no-haptic setup involves just a big TV screen which is much easier to set up. Furthermore, figures 25 and 26, also show that for hedonic quality, the haptic setup was benchmarked as *Excellent* but for no-haptic setup, it was just *Above Average*. This means that the participants enjoyed the haptic interaction a lot. But it could be due to the novelty effect caused by the haptic sleeve itself. Another reason could be that the participants might be used to MS Teams, and therefore do not find it as attractive as the entire haptic setup.

These results show that there is a high likability for the haptic setup which is quite novel for the participants, but further research is required on the design and practicality of the setup.

10.2 ANSWERING THE RESEARCH QUESTIONS

In this thesis, several topics were discussed to answer the following research question:

How does a vibrotactile sleeve affect the perception of presence with the other during remote communication in affective relationships?

To answer this question, sub-questions have been formulated (see section 1.1). This section discusses the answer to these sub-questions, connects it to relevant sections, and finally answers the main question.

What is meant by perception of presence?

Perception of presence has been explained in section 5.1. Perception of presence or social presence is defined as the judgement of perception of the other partner [74]. In simple terms, it means up to what level can a person judge their ability to feel the other in the same virtual environment. The virtual environment may be something as elaborate as a virtual world or even as simple as a video call.

How to measure the perception of presence?

Section 8.4 explains how social presence is measured. Holistic social presence questionnaire measures the quality of experience of mediated social presence. It measures the quality of experience from a

bi-directional (self and other) perspective of the user. Networked minds questionnaire measures the psychological involvement in social presence through its empathy and mutual understanding scales.

What is the state of the art in vibrotactile sleeves?

Section 6 is devoted to answering this question. Technologies from both tactile and kinaesthetic were studied. It was seen that vibrotactile devices using coin ERM motors are suitable for haptic sleeves. Among the devices that use coin ERM motors, the bespoke vibrotactile sleeve from the University of Twente was chosen to be a part of this study since it is very flexible, customizable, and lightweight.

How does this setup affect people in terms of social presence?

Section 11.2.1 discusses the effect of the setup on social presence. It was seen that there was no significant effect found between haptic and no-haptic conditions. The data yielded inconclusive results. However, the scores of social presence in both conditions were above 5 suggesting that social presence was indeed affected, but the reason why it was affected is inconclusive. Based on the discussion, the possible reasons could be: 1) the life-size view of the partner increased the overall social presence score, 2) haptic interaction draws the participant's attention, which breaks immersion and in turn reduces the score.

What added effect does the vibrotactile sleeve bring to the remote communication?

Based on the emotion state results seen in section 11.2.2, it can be said that the vibrotactile sleeve was successful in providing a comforting feeling to its user. At the start of the experiment, the participants were shown a video of sad nature, following which they had a conversation about sad personal events. By the end of the experiment, participants in the haptic condition had lesser scores for feelings of sadness, scared, and wanting. Therefore, this sleeve could be useful for future studies related to mediated touch and empathy.

How does a vibrotactile sleeve affect the perception of presence with the other during remote communication in affective relationships?

Participants of this study were pairs of individuals who are in affective relationships with each other. The results suggest that, while there is a positive effect of the vibrotactile sleeve perceived by the user during a remote communication, nothing can be said for social presence since the results are inconclusive. The positive effects are related to participants feeling comforted and the overall user experience of the setup. More study and research is required to further determine the effect on social presence.

11 LIMITATIONS AND LESSONS

Despite an experiment being conducted in a controlled environment, there arise some limitations related to the lack of literature, availability of state-of-the-art devices, researcher error in methodology, or some random worldly factor that is impossible to control. These limitations may possibly negatively influence the results. For future research, these limitations could serve as guidelines on what to do and what not to do. Likewise, this experiment had several limitations. This section shall outline what these limitations were and discuss their implications on the results.

Network delays – The experiment used two laptops to run MS Teams. These laptops were connected to the same router. VideoLAT was used to measure the network latency for Teams. Figure 27 shows that the audio-video latency was ~360ms. A similar test for measuring haptic response delay saw a delay of ~200ms. According to the international telecommunication union, a 400 ms mouth-to-ear delay causes many users to be dissatisfied with the experience [114]. Tam et al. [115] state that under 500ms, users have a slightly negative effect on naturalness due to this delay. Before the experiment, measures were taken to reduce the latency, but they failed to prove useful.

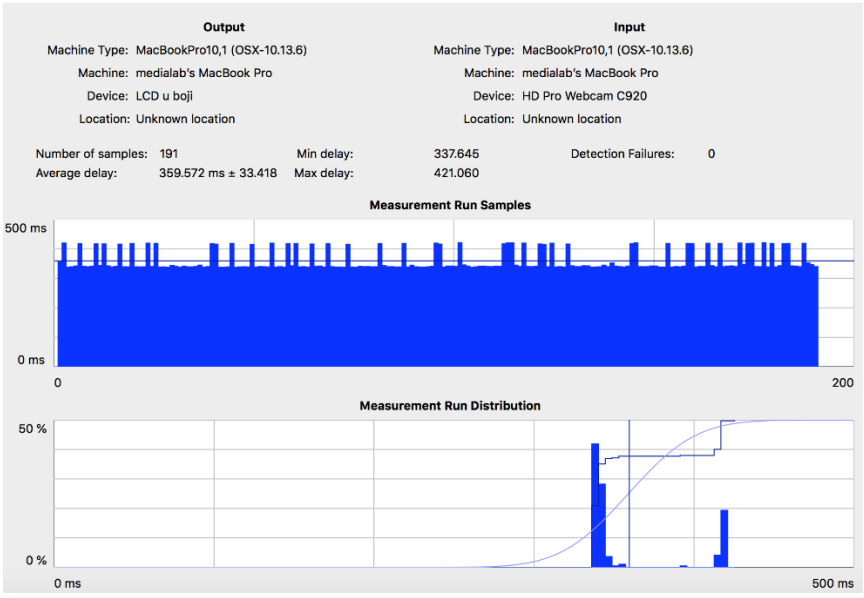


Figure 27. VideoLAT results

Lack of video recording – For the sake of participant privacy, video recording was not considered necessary. This however came with a trade-off. No video recordings meant no possibility to analyse non-verbal communication. Non-verbal information could have been useful to understand how the participants interacted with the system, whether they conversed naturally, with gestures, or showed emotions. It could also have shown if the quality of the video call dropped or how they reacted to the haptic interaction. All the interaction happened behind closed doors which meant the participants were comfortable discussing whatever they felt but nothing else except the questionnaire data was accessible. Therefore, video recordings are essential in such an experiment since it provides plenty of non-verbal information.

Indication by knock – Another issue due to a lack of video recording was the indication by knocking. To make sure the participants interact with the system at least twice during the experiment, participants in the room with the mannequin arm were indicated to touch it. The indication was a knock on the door. However, since there was no way to listen or see which would be a perfect moment to indicate the participant to touch, two indications were given at 5-minute intervals. This method is not accurate as it can be that a knock can occur at a seemingly random time and the participant is forced to touch the other when it is completely inappropriate. It can also be that the knock is not heard by the participant A solution could be that the participants are free to touch whenever they feel like it, and the resulting haptic interactions could be logged through a program. The interaction would now be analysed through the logged data. Doing so could eliminate the need for knock and the interaction would now be more natural.

Various videos – To simulate a scenario where the participants provide comforting touch, videos were shown that consisted of elements of death, grief, or hardship. This was done to induce sadness among participants. Video stimuli are proved to be better at inducing sadness [98] and the selected videos (Table 1) were all proved to induce sadness [99]. However, there were five different selected videos which were shown to the participant cyclically (Pair 1,6,11 – video 1, pair 2,7,12 - video 2, …). This added a big random effect since the videos are all different and their effects could be different across participants. To make the experiment feasible, the effect of all five of these videos was assumed to be the same. This is a rather delicate assumption. The best scenario would be to show just 1 video to all participants.

Video*conversation effect – 2 questionnaires, one before watching the video and the other after the conversation task were recorded. The first questionnaire contained the emotion scale and the second contained emotion, social presence, and user experience scales. The effect of emotion measured was over the whole course of the task, which was video*conversation. This meant the questionnaire data recorded the effects of conversation compounded by the video. This also meant any comforting interaction whether haptic or no-haptic that occurred during the conversation task was compounded by the video. Therefore, the social presence measured was the effect of video*conversation and not just conversation. A solution would be to add an intermediary questionnaire that measures emotion after the video was watched and before the conversation starts.

Video echoes – Participants were given tablets on which they could watch the video. The audio setup was managed carefully such that there were no echoes from both sides. However, when they watched the video, the audio echoed and the participants either reduced their volume or used their personal headphones. This might have caused unwanted irritation and emotional changes in the participants. It is important to note that the videos could not be shown on the TV screen due to two reasons – 1) participants should be able to always see each other to not break immersion, 2) any movement on the screen caused the title bar and teams menu to reappear which meant the participants cannot see each other in full screen anymore. A solution here would be to provide a pair of headphones to the participants.

Uneven gender pair combination – Table 2 shows the gender pair distribution of the participants. It can be seen that the participants between haptic and no-haptic were not evenly distributed for each pair.

Pair type	Sender of Touch	Haptic	No-haptic
Male-Male	Male	4	3
Female-Female	Female	1	2
Female-Male	Female	2	3
Male-Female	Male	4	3

Table 5. Gender pair distribution

Novel technology – Haptic sleeves are not a widely used technology. Therefore, novelty effect could play a role. Participants could be enthralled by the sleeve and the arm such that it would become distracting whenever they interact with the haptic setup. Such a distraction could cause a break in immersion. Participants were given 5-10 minutes to try out the system and get used to it. However, it might not have been enough.

12 CONCLUSION

This report has shown that a major issue related to the absence of touch interaction in mediated communication exists, the effects of which were exacerbated due to social distancing, long-distance relationships, or isolation. Research in mediated touch technologies has shown a promise in alleviating such issues but it is still in its infancy. Every day, more people use remote communication and even other haptic devices are developed. Therefore, this gives researchers a better opportunity to study, develop, and validate these devices concerning mediated social touch, emotion, and presence. Doing so is a necessity to avoid another iteration of touch starvation in the future, ultimately improving the quality of life.

This study tries to answer if and how people perceive the presence of their partners in remote communication when using a vibrotactile sleeve. Studying various literature helped understand the context of this study further, mainly – why touch is essential in a social scenario, how to mediate social touch, the significance of social touch in comforting someone, what is social presence and how does it play a role in mediated communication. The setup and interaction were designed based on certain criteria. It included a bespoke vibrotactile sleeve that was used to emulate touch. Since people are more comfortable talking with others whom they know well, only pairs of close friends, partners or family will be invited for the study. Social presence will be measured along with the emotional state of the participants and user experience.

22 pairs of individuals participated in the study. These pairs were individuals who are in affective relationships with each other. The results of this experiment reveal that there is a positive overall effect of the vibrotactile sleeve during mediated communication. However, social presence data yielded inconclusive results. Therefore, nothing can be said about the effect of a vibrotactile sleeve on social presence. The positive effects are related to emotion state and the overall user experience of the participants. The sleeve was able to provide comforting touch to the participants. Positive overall user experience scores in both conditions suggest that participants liked the life-size view of each other. These results show that there is a high likability for the haptic setup which is quite novel for the participants, but further research is required on the design and practicality of the setup. As such, the limitations and lessons learnt from this study are drawn which could be helpful for future research.

Finally, it can be concluded that a lot of research still needs to be done in the field of mediated social touch. The outcomes of this study could serve as a stepping stone for future research.

SUMMARY

The onset of social distancing due to COVID-19 caused touch starvation in individuals. This study also saw that social distancing and isolation are one of the bases of pandemic prevention that have been used in other situations as well [11]. Although it proves to be useful, it takes a huge toll on certain individuals starving them of touch. People are denied interaction through an intimate form which, research shows, could lead to neurodevelopmental and cognitive delays [13,14], higher depression scores [6]–[8], increased physiological stressors such as blood pressure, breathing rate, etc. [10].

Research shows social touch is a method to tackle this problem (section 4). This thesis studied how a body reacts to social touch in terms of its psychological and physiological effects on the body. Despite the observable effects on the body, it was also seen that the context of that touch played a major role in the immediate response to social touch. Social touch varied depending on the toucher's characteristics as well as the situational factors [45]. Figure 2 summarizes the potential psychosocial and contextual factors that affect the touch response. Furthermore, the effect of social touch with empathy was investigated. It was clearly seen that social touch had a positive effect on empathy, acting as an analgesic [48]. In combination, these effects evidenced the positive nature of social touch in providing a healing effect, provided the subjects were touched in socially acceptable places (see Fig. 3). Forearms were observed to be the common region where people in affective relationships such as friends, family or romantic partners are allowed to touch [51].

This thesis also discussed the various types of touches seen in real social interaction (section 4.5) and how to mediate it through technology (section 3). Therein the use of haptics, its various types and affective haptics were discussed. Affective haptics deal with haptic devices that can be used in the context of emotions [21]. They have been proved useful to treat depression [22], act as an assistive system for children with autism [23] and have also been used in health applications [24]. Such devices could also be useful in comforting someone while being far away [28,116].

Section 5 discusses social connectedness and its effects on humans. It was found that social connectedness is linked to the ability to understand others, participate in social activity, and feel empathy. This thesis also discusses social presence and the difference between social connectedness and presence. Social presence relates to the judgement of perception of others whereas social connectedness relates to the emotions evoked due to the other's presence. This difference strongly suggests focusing on presence for this study as it seems more relevant to the present scenario.

Among the different types of haptics studied in section 6, vibrotactile devices, specifically coin ERMs were deemed suitable for this study due to their technological maturity, availability, and bulkiness. Furthermore, various other state-of-the-art vibrotactile sleeves were studied on their use case, functionality, and results. It was seen that the bespoke vibrotactile sleeve was suitable for this study due to its advantages.

To conduct the study with participants, a setup is required to be designed and constructed. The design process was divided into designing the setup and designing the interaction. For designing the setup, the following decisions were taken:

- Corner table – A regular table with edges
- Video call software – MS Teams
- Life-size view – 46-inch portrait TV with a TV stand
- Eye contact – Camera with gooseneck hung from top of TV at eye-level
- Background continuation – 2 identical-looking office spaces with white background
- Directional sound – 2 angled speakers behind the TV

For designing the interaction,

- Visible limb – Mannequin arm
- Patting/Holding touch – Easily programmable
- Out-of-view touch – Place arm near edge of table

Section 8, the methodology section describes the events and timeline of the experiment and the stimulus (Table 1) that would be shown to the participants. It also includes a description of the participants. Section 8.3 explains the procedure of the experiment and how it will be conducted. Section 8.4 explains the various questionnaires that shall be used to record the responses of the participants. Since the participants are not being recorded in any form, there is no way to determine when the participants do (not) interact using the mannequin arm. Therefore, a knock was determined a viable way of notifying the participants to interact with the mannequin arm. This ensures, that the participants do interact with the haptic setup.

Section 10 discusses the results of the experiment provided in section 9. The results of social presence were deemed inconclusive because of the insignificant difference between haptic and no-haptic conditions. However, both conditions scored high, which suggested a positive effect of using a life-size view of the partner [110]–[112]. A basic before-after comparison in each condition revealed that haptics has reduced scores of both sadness and grief (Fig. 23 Haptics) when compared to no-haptic (Fig. 23 No-haptics). This was anticipated because touch is better suited to comforting someone in distress [29,45]. Figure 24 explains the jump in emotions before and after the experiment. It showed a negative jump in sadness, scared, and wanting in the haptic condition than in the no-haptic condition. The results for user experience showed that users liked both the setups but there is a higher likability for the haptic setup. Figure 25 and 26 shows a user experience benchmark of the setup. Finally, section 10.2 answers the research questions of this study. The limitations and lessons learned from this study are addressed in section 11. The limitations were related to network delays, methodology issues, and novelty effects.

In conclusion, this thesis provides a basis for measuring social presence using mediated social touch. The lessons learnt from this study could prove useful for future research.

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APPENDIX

A DEVICE SUMMARY

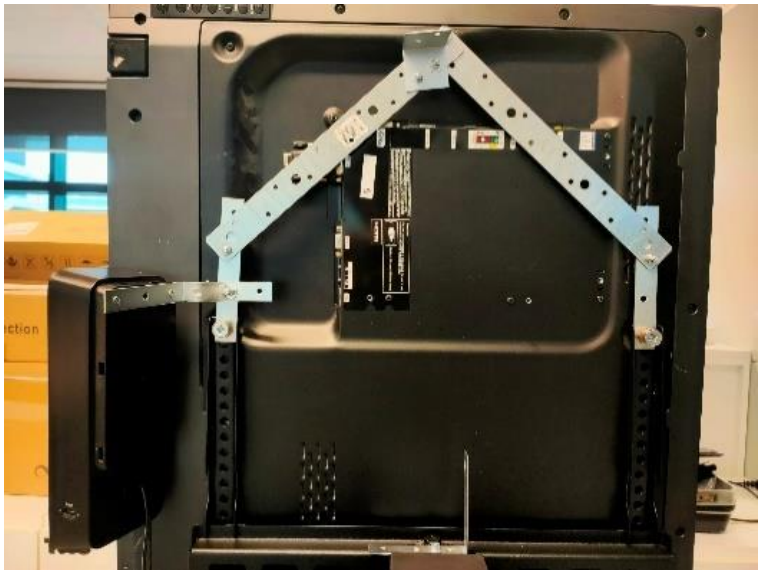
Device	Area of effect	Type of Haptic	Interaction type	Advantages	Disadvantages
TaSST	Forearm	Vibrotactile	Poke, Hit, Press, Squeeze, Rub, Stroke	2-way communication	Bulky, High part complexity, 1 prototype available
bHaptics Tactosy	Lower forearm	Vibrotactile	Hit, Rumble	Easy to set up, wireless	Limited programming options
Elitac Emotion Sleeve	Full arm	Vibrotactile	Taps, Strokes	Wide variety of interaction patterns	Very specific use case, Dependent on an app and smart glasses
Vibration sleeve	Forearm	Vibrotactile	Stroke, Pat	Adjustable, Programmable, lightweight	Specific use case, 1 prototype available
Ultrahaptics	Palm, Foot sole	Ultrasonic	Stroke, Poke, Rub, Pat	Contactless touch, Not a wearable	Expensive, Heavy, User training required
Elitac-manus glove	Hand	Vibrotactile	Hit, Press,	Programmable, multiple contact points	High part complexity
McKibben actuator	Forearm	Kinaesthetic	Press, Squeeze, Hold	Provides a light force for touch	Bulky, Loud, High part complexity

B DESIGN ITERATIONS

Design iterations contains the different design decisions and iterations that were done regarding the audio setup, camera placement, and TV placement.

Audio setup

Various ways were tried to focus the audio on the user.

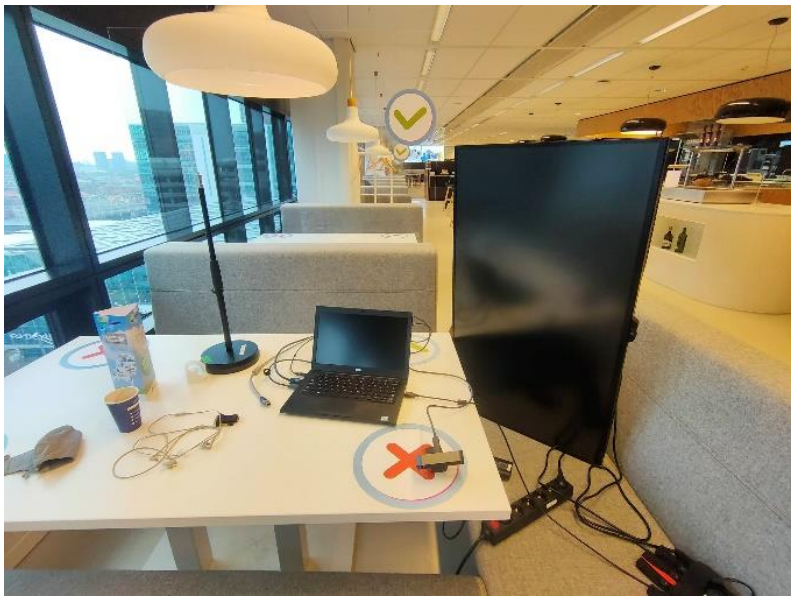


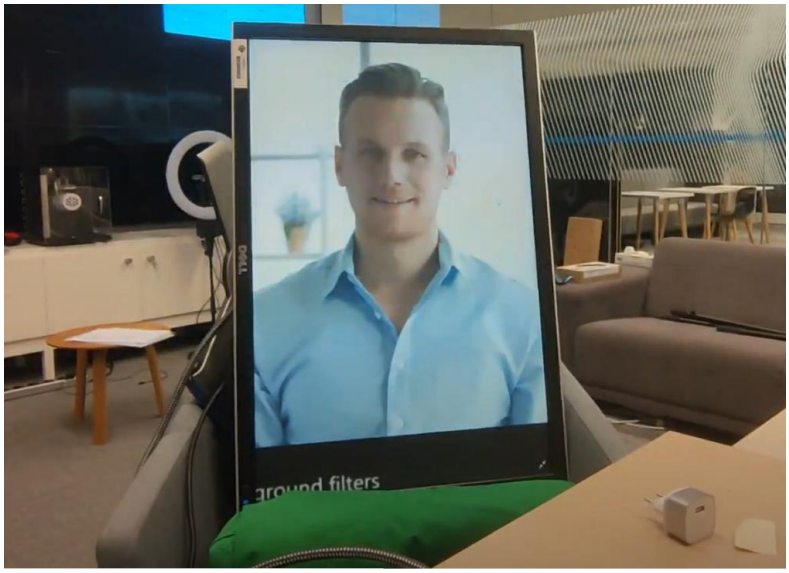
Camera Placement

The camera should be at the eye level but should not distract the user.

TV Placement

Comfortable viewing angle for a corner table





C QUESTIONNAIRE

Start of Entry Questionnaire

I1

Hello! Thank you for participating in my experiment.

This questionnaire is divided into 2 sections. The first section consists of one question that you answer before doing the experiment. You must do the second section after the experiment and it consists of four subsections.

All the instructions are provided in this questionnaire itself but in case of any issues please contact me. Remember, you can choose to stop the experiment at any point of time.

Good luck! 😁 👍

Note: All questions are mandatory

Participant ID (ex: pc992, pe631)

_____

EQ1 To what extent are you feeling these emotions right now?

	Not at all (1)	Slightly (2)	Somewhat (3)	Moderately (4)	Quite a bit (5)	Very much (6)	An extreme amount (7)
Sad (1)	○	○	○	○	○	○	○
Grief (2)	○	○	○	○	○	○	○
Worry (3)	○	○	○	○	○	○	○
Dread (4)	○	○	○	○	○	○	○
Nervous (5)	○	○	○	○	○	○	○
Empty (6)	○	○	○	○	○	○	○
Lonely (7)	○	○	○	○	○	○	○
Anxiety (8)	○	○	○	○	○	○	○
Scared (9)	○	○	○	○	○	○	○
Fear (10)	○	○	○	○	○	○	○
Wanting (11)	○	○	○	○	○	○	○

I2

Please proceed to watch the video.

You can access the video in the Gallery (bottom of home screen). If you can't see the video in the app, press the 3 horizontal bars on top-left of screen and select 'Videos'.

Please continue to the next section only **after watching the video**.

I3

After you watched the video, you can now have a conversation with your experiment partner.

You must talk about events that made you feel sad. This can be any event from your personal experience that made you feel sad. For example, a loss of a loved one, a tragic accident, natural disaster, unmet expectations, over stress, etc.

You can use the prompts from the paper in front of you, if you have trouble describing the event. Although you do not have to stick to the prompts. Use whatever language you feel comfortable to talk.

Take up to 15 minutes to complete the conversation. If you feel there is nothing more to speak then you can proceed to the next section.

Press next once you finish the task.

I4

Make sure you have **finished the task** before proceeding to the next section.

End of Entry Questionnaire

Start of Exit Questionnaire

XQ1
Part ¼

Please answer the following questions with respect to how you and your partner seem to see, hear, feel each other without any restrictions or distortions

	Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neutral (4)	Somwehat agree (5)	Agree (6)	Strongly agree (7)
I have direct contact with the other person. (1)	○	○	○	○	○	○	○
I feel engaged with the other person. (2)	○	○	○	○	○	○	○
The other person appear natural to me. (3)	○	○	○	○	○	○	○
I can interact with the other person in a natural manner. (4)	○	○	○	○	○	○	○
The other person affects my thinking as in normal life. (5)	○	○	○	○	○	○	○
The other person appear to have direct contact with me. (6)	○	○	○	○	○	○	○
The other person appear to feel engaged with me. (7)	○	○	○	○	○	○	○

I seem to appear natural to the other person(s). (8)	○	○	○	○	○	○	○
The other person interact with me in a natural manner. (9)	○	○	○	○	○	○	○
I appear to affect the thinking of the other person as in normal life. (10)	○	○	○	○	○	○	○
When I was sad, the other was also sad. (11)	○	○	○	○	○	○	○
When the other was sad, I was also sad. (12)	○	○	○	○	○	○	○
The other individual was influenced by my moods. (13)	○	○	○	○	○	○	○
I was influenced by my partner's moods. (14)	○	○	○	○	○	○	○
The other's mood did NOT affect my mood/emotional-state. (15)	○	○	○	○	○	○	○
My mood did NOT affect the other's mood/emotional state. (16)	○	○	○	○	○	○	○

My opinions were clear to the other. (17)	○	○	○	○	○	○	○
The opinions of the other were clear. (18)	○	○	○	○	○	○	○
My thoughts were clear to my partner. (19)	○	○	○	○	○	○	○
The other individual's thoughts were clear to me. (20)	○	○	○	○	○	○	○
The other understood what I meant. (21)	○	○	○	○	○	○	○
I understood what the other meant. (22)	○	○	○	○	○	○	○

XQ2
Part 2/4

While undergoing the emotional experience, e. g., viewing the video, having the conversation, etc., to what extent did you experience these emotions?

	Not at all (1)	Slightly (2)	Somewhat (3)	Moderately (4)	Quite a bit (5)	Very much (6)	An extreme amount (7)
Sad (1)	○	○	○	○	○	○	○
Grief (2)	○	○	○	○	○	○	○
Worry (3)	○	○	○	○	○	○	○
Dread (4)	○	○	○	○	○	○	○
Nervous (5)	○	○	○	○	○	○	○
Empty (6)	○	○	○	○	○	○	○
Lonely (7)	○	○	○	○	○	○	○
Anxiety (8)	○	○	○	○	○	○	○
Scared (9)	○	○	○	○	○	○	○
Fear (10)	○	○	○	○	○	○	○
Wanting (11)	○	○	○	○	○	○	○

XQ3
Part 3/4

Select the option from the range that best describes how you experienced the setup.

	1	2	3	4	5	6	7	
Obstructive	○	○	○	○	○	○	○	Supportive
Complicated	○	○	○	○	○	○	○	Easy
Inefficient	○	○	○	○	○	○	○	Efficient
Confusing	○	○	○	○	○	○	○	Clear
Boring	○	○	○	○	○	○	○	Exciting
Not interesting	○	○	○	○	○	○	○	Interesting
Conventional	○	○	○	○	○	○	○	Inventive
Usual	○	○	○	○	○	○	○	Leading edge

I5
Part 4/4

The following questions are related to demographics. These are mandatory since it helps understand how the effect of this experiment varies for different demographics.

Please choose the option that best suits you.

XQ4 What is your age?

_____

XQ5 What is your gender?

- ○ Male (1)
- ○ Female (2)
- ○ Non-binary / third gender (3)
- ○ Others (4)

End of exit questionnaire

D CONVERSATION PROMPT

Take up to 15 minutes to complete the task. Use whatever language you are comfortable to talk.

Describe an event that made you feel sad. This can be any event from your personal experience that made you feel sad. For example, a loss of a loved one, a tragic accident, natural disaster, unmet expectations, over stress, etc.

Below are certain prompts that you can use if you think you need to elaborate more. You can choose not to follow the prompts as well. Talk whatever you want to about the event.

- When it was?
- What and/or how it happened?
- What did you feel when it happened?
- Where were you then?
- Who was involved?
- What happened next?
- How do you feel about it now?

E User Experience Scores

No haptics

Scale	Subscale	Negative	Positive	Mean	Evaluation
Pragmatic Quality	Dependability	Obstructive	Supportive	1.3 ± 1.5	Positive
	Perspicuity	Complicated	Easy	1.9 ± 1.3	Positive
	Efficiency	Inefficient	Efficient	1.6 ± 1.7	Positive
	Perspicuity	Confusing	Clear	2.3 ± 0.9	Positive
Hedonic Quality	Stimulation	Boring	Exciting	1.2 ± 1.3	Positive
	Stimulation	Not interesting	Interesting	1.5 ± 1.4	Positive
	Novelty	Conventional	Inventive	0.7 ± 1.5	Neutral
	Novelty	Usual	Leading edge	0.2 ± 1.6	Neutral

Haptics

Scale	Subscale	Negative	Positive	Mean	Evaluation
Pragmatic Quality	Dependability	Obstructive	Supportive	1.4 ± 1.3	Positive
	Perspicuity	Complicated	Easy	1.7 ± 1.7	Positive
	Efficiency	Inefficient	Efficient	1.3 ± 1.2	Positive
	Perspicuity	Confusing	Clear	2.0 ± 1.2	Positive
Hedonic Quality	Stimulation	Boring	Exciting	1.6 ± 1.0	Positive
	Stimulation	Not interesting	Interesting	2.0 ± 1.0	Positive
	Novelty	Conventional	Inventive	2.0 ± 1.0	Positive
	Novelty	Usual	Leading edge	1.3 ± 0.9	Positive