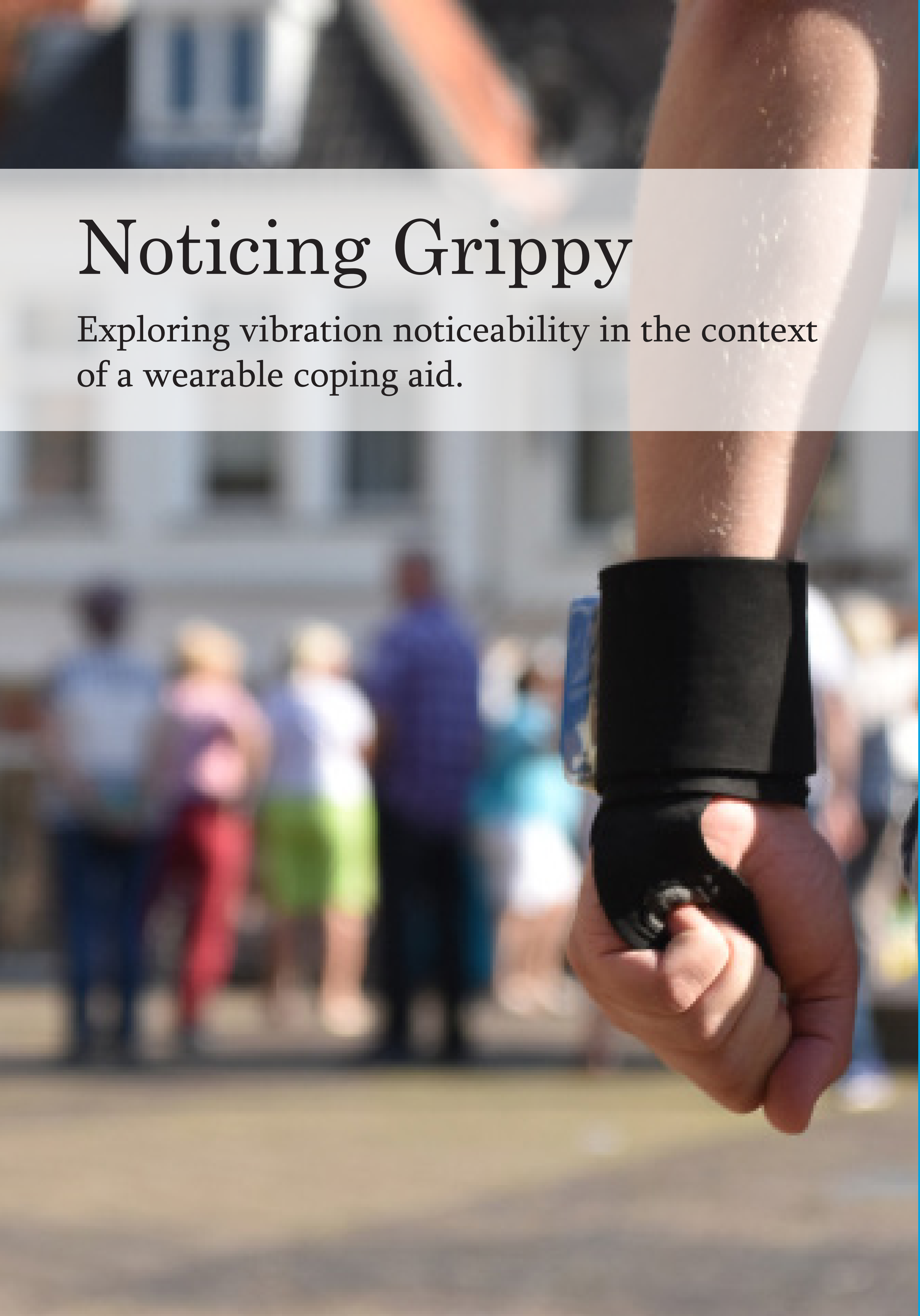
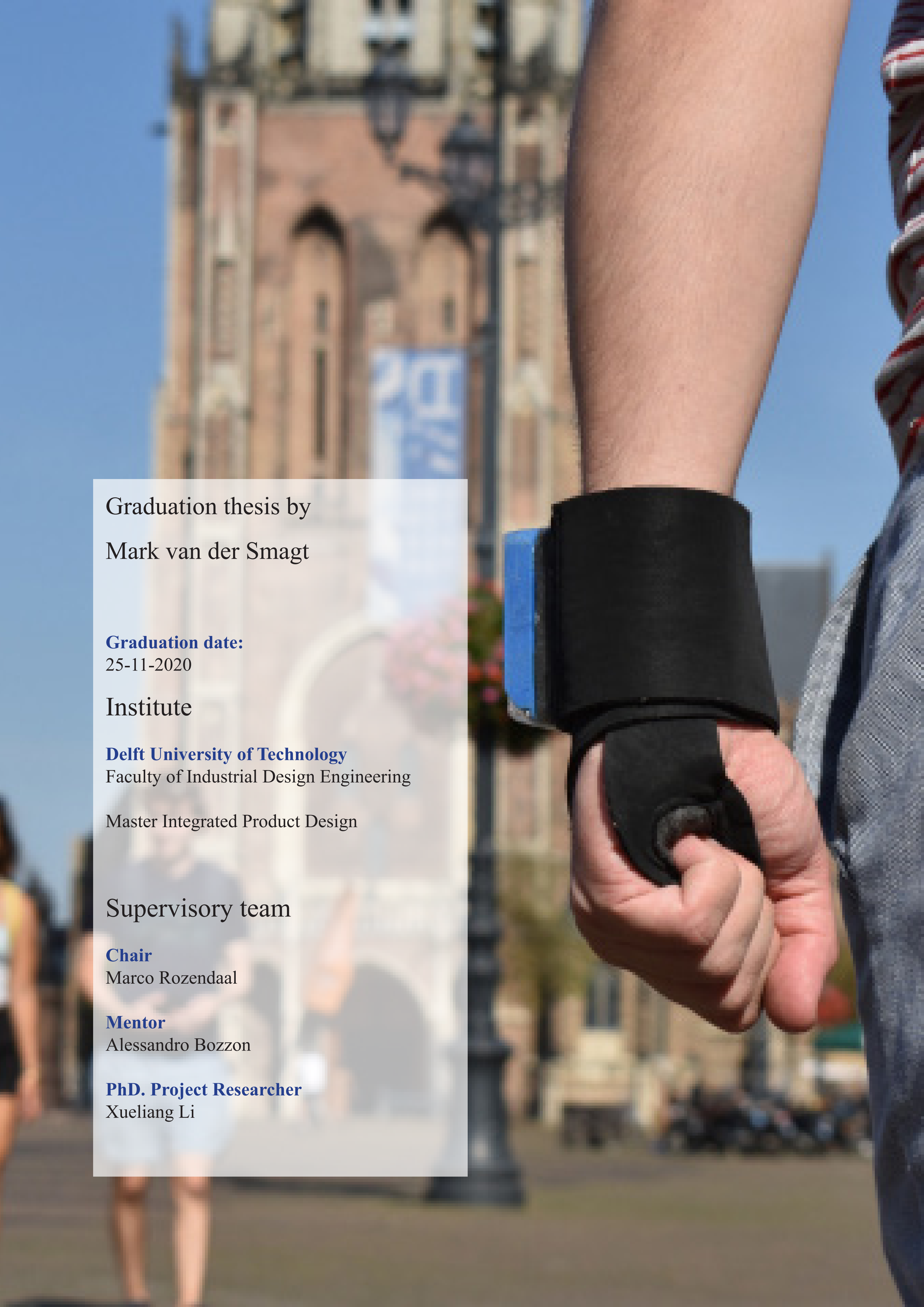


Noticing Grippy

Exploring vibration noticeability in the context of a wearable coping aid.



Graduation thesis by

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Aknowledgements

Dear reader, this document before you is the result of a lot of hard work, critical thinking and plenty of support. During the Covid-19 pandemic, we all see fewer people, but I have many people to thank.

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There are three other persons I would like to thank personally. Douwe, with whom I had regular calls about life, graduation and other stuff. Bram who helped me greatly with the pictures and footage of Grippy. And Eveline who was a great supporter and advisor in all stages of the project.

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Finally, I would like to thank my parents, Steven and Miebet, whom I can see as I am currently writing these last few sentences, for the endless supply of cappuccino and all the support throughout the project.

Mark

Abstract

Daily stress is a problem that many people are suffering from. In previous research a prototype was developed to help users to identify their own stressful places and encourage them to conduct self-training exercises in those locations. This prototype is called 'Grippy'. The goal of this project is to explore what qualities Grippy's vibration signal should have, to appropriately warn the user of upcoming stress. Three knowledge gaps are identified. First, how the vibration strength of the signal influences the noticeability, audibility and disruption of the vibration signal. Second, what environmental factors influence the noticeability of wrist-mounted vibration signals. And third, how we could design respectful vibration signals that grab the users attention.

Three experiments have been performed. Experiments one and two used 14 and 7 participants respectively to measure at which vibration strength Grippy's vibration signals are noticeable to the user and bystanders respectively. With the insights from these two experiments, a new stress alert signal is proposed. This signal is tested in a third auto-introspective experiment. In this experiment we also explore 'how Grippy fulfils the qualities of wearable partners in daily life'.

The proposed stress alert signal is found to be discreet and respectful in most situations. These include social situations like presenting, listening and talking, but also shopping, walking, studying and playing piano. During cycling the proposed stress alert signal was not consistently noticeable. In addition, short disruptions in the environment such as arm movement and gusts of wind could temporarily distract from or mask the vibration signal.

This report concludes that a continuous vibration signal at a fixed vibration strength is likely an appropriate way of alerting users in most situations, but that adaptation of the vibration strength to detect cycling like situations will be necessary.

Figure 1: *Grippy worn while cycling*

Table of Content

Section 1: Introduction

1.1 Assignment

1.1.1 Assignment

Daily stress is a problem that many people are suffering from. Exposure therapy, as introduced by Rothbaum & Schwartz (2002), can help these people overcome stressors. However, currently exposure therapy is limited to controlled settings such as virtual reality as explored by Rizzo et al (2013). If we can create a wearable device which allows users to safely expose themselves to their stressors in daily life, that would give patients more freedom and help throughout the coping process.

This project is part of a larger PhD project that is focussed on designing smart wearables for coping. Previously a prototype was developed: 'Grippy'. Grippy can sense the user's stress, alert the user of upcoming stress through just-in-time notifications and help the user cope. The goal of this project is to explore what qualities Grippy's vibration signal should have to appropriately send just-in-time notifications.

1.1.2 Educational Goals

Four learning objectives were set at the start of the project. These objectives represented approaches and area's I wanted to explore more during my graduation. As they did not evolve over the course over the project they remain quite vague. In chapter 6.3 'Learning Objectives' I will discuss the realisation of these learning objectives.

Design some form of an intelligent system
The original proposal of the graduation project would have Grippy construct a digital model of the user with the data it collects during use. This model could then be used to personalise Grippy. I was interested in either building this model or explore what it could be used for.

Work and continue on existing software
I liked to work on an existing project and add to already existing code. As I felt that that would be a great measuring stick to compare my programming to the 'real world'.

Work hands-on with a prototype
For many of the same reasons as with 'working on existing software', I wanted hands-on experience with lessons I learned during my study. There were a few times in my study where I was able to iterate on a single prototype.

Do fast iterations
While many courses in 'Integrated Product Design' offer the full design process in a single course, few courses involve iterations in the learning process. For this project, I wanted to use a research through design process with multiple iterations.

1.2 Subject - Grippy

1.2.1 Grippy

Grippy is a combination of a glove like wearable and a phone application. Grippy can sense the user's stress, alert the user of upcoming stress through just-in-time notifications and help the user cope better with stress.

During the onset of stress, the user will be asked if he or she is "OK". This prompts the user to become aware of his or her current stress level. The user will then respond by indicating his or her stress level to Grippy. If the user is stressed Grippy will help the user cope with oncoming stress as instructed by his therapy. Additionally, Grippy will remember the location as a stressful location.

The stressful locations will be shown in forms of an annotated map on the phone which the user can view at any time. Grippy will also warn the user when he or she is near an area where stress has been reported in the past. If the user is at a location he has previously experienced as stressful, Grippy will encourage the user to go for a "challenge". A 'challenge' or self-training session is a moment where the user consciously decides to expose themselve to stressors. By being aware of the stressors, and by observing it, the user can try to overcome the stress.

The measurements and the interaction with the user are done by the Grippy glove. To do this, the Grippy glove consists of a vibration motor, a heart-rate sensor, an accelerometer, a button, and a pressure sensor.

This thesis report will focus mainly on the interaction with the Glove portion of Grippy. The goal of this project is to explore what attributes Grippy's vibration signal should have to appropriately warn the user of upcoming stress. In the paper titled 'Things that help out', Li et al (2020) describe the benefits of treating wearables as 'partners' and the three qualities that define wearables as a partner. These are trustworthiness, discreetness, and respectfulness, which will discussed further in chapter 2.3. However, these qualities have not yet been translated to the design of vibration signals Three knowledge gaps can be identified, which will be explained in the next subchapter.

Figure 2: Pressing the button after noticing the vibration signal.

1.2.2 Knowledge gaps

Sonneveld & Schifferstein (2008) defined three factors for influencing the tactual experiences of a product, which is in our case a vibration signal. These are strength, location and pattern. This thesis will focus on the strength of the vibration signal. The placement of the vibration motor is fixed on the prototype, and for the noticeability of the vibration, signal strength is assumed to be the most influential factor. Three knowledge gaps have been defined.

The relation between vibration strength, noticeability, audibility and disruption.

The vibration strength thresholds at which Grippy's vibration signal becomes noticeable to the user and becomes audible to others is poorly understood. Additionally, we want to learn whether disruption caused by the vibration signal might make signals inappropriate before they stop being discreet.

Environmental factors that influence vibration signal noticeability

One of the problems that arises when we are trying to adapt vibration strength to send a just-noticeable vibration signal is that we do not know which factors influence the user's ability to notice vibration signals. Mapping these distractors becomes more relevant when we look at just-noticeable vibration signals.

How to design respectful stress alerts

As described in the previous chapter, respectful stress alerts should tell the user situation-specific information and not disrupt the user. However, the stress alert intervention might be, by nature, disruptive to the user. Additional insights are needed into how to design vibration signals that can be accurately discerned from each other, but also not Disrupt the user.

Figure 3: Using the pressure sensor to record stress level while outside.

1.3 Experiments

To explore the research gaps laid out in the previous chapter, three experiments have been performed. Experiments 1 and 2 used participants to measure at which vibration strength Grippy's vibration signals are noticeable to the user and bystanders respectively. With the insights from these experiments, a new stress alert signal is proposed. This signal is tested in the third experiment in addition to exploring how Grippy fulfils the qualities of wearable partners in daily life. Which will be described in chapter 2.3

1. Vibration noticeability in stressful social situations

The first experiment aimed to find out at what vibration strength Grippy can be noticed in social environments. Fourteen participants were placed in a video call with two 'judges' and the researcher. During the video call, the participant had to perform various social tasks such as listening to, presenting for and having small-talk with the 'judges'. While the participants were busy with the social tasks, vibration signals of differing strengths would be sent by the Grippy glove. The participants had to repeat the patterns of these vibration signals, at the moment they came in.

Results showed that all participants were able to notice each vibration signal in each situation at 40% of the maximum vibration strength and above. This indicates that the lower threshold on vibration strength is at 40% of the maximum vibration strength of the used vibration motor. This signal strength is referred to as the 'low strength' signal.

2. Vibration audibility in quiet environments

The second experiment aimed to find out at what vibration strength bystanders can hear Grippy in a quiet environment. Seven participants are seated in a quiet room at 50cm - 100cm distance from a Grippy glove worn by the researcher. Vibration signals at increasing strength are sent to the researcher and the participants are asked to call out when they hear a signal.

The low strength signal described in experiment one came out discreet, indicating that a vibration signal at that vibration strength would be noticeable and discreet in most situations. Therefore being a potentially always appropriate signal in terms of noticeability and discreetness.

3. Receiving vibration signals in daily life

The third experiment aimed to explore whether a non-adaptive vibration signal could be appropriate and noticeable in all daily situations in addition to how Grippy fulfils the three qualities of partners in daily life. A researcher introspection was conducted. The researcher wore Grippy for longer periods and performed various daily tasks. A proposed continuous vibration signal which came out of the first two experiments was tested. This continuous vibration signal would be sent at pseudo-random intervals averaging 20 minutes. The researcher would respond to these signals and record his feelings and the environment in writing.

This relatively weak vibration was found to not be Disrupting to the user and noticeable in most situations. However, the vibration signal could be temporarily less noticeable when something unexpected happened just as the signal arrived. This indicated that a both continuous and adaptive vibration signal might be necessary.

1.4 Project structure

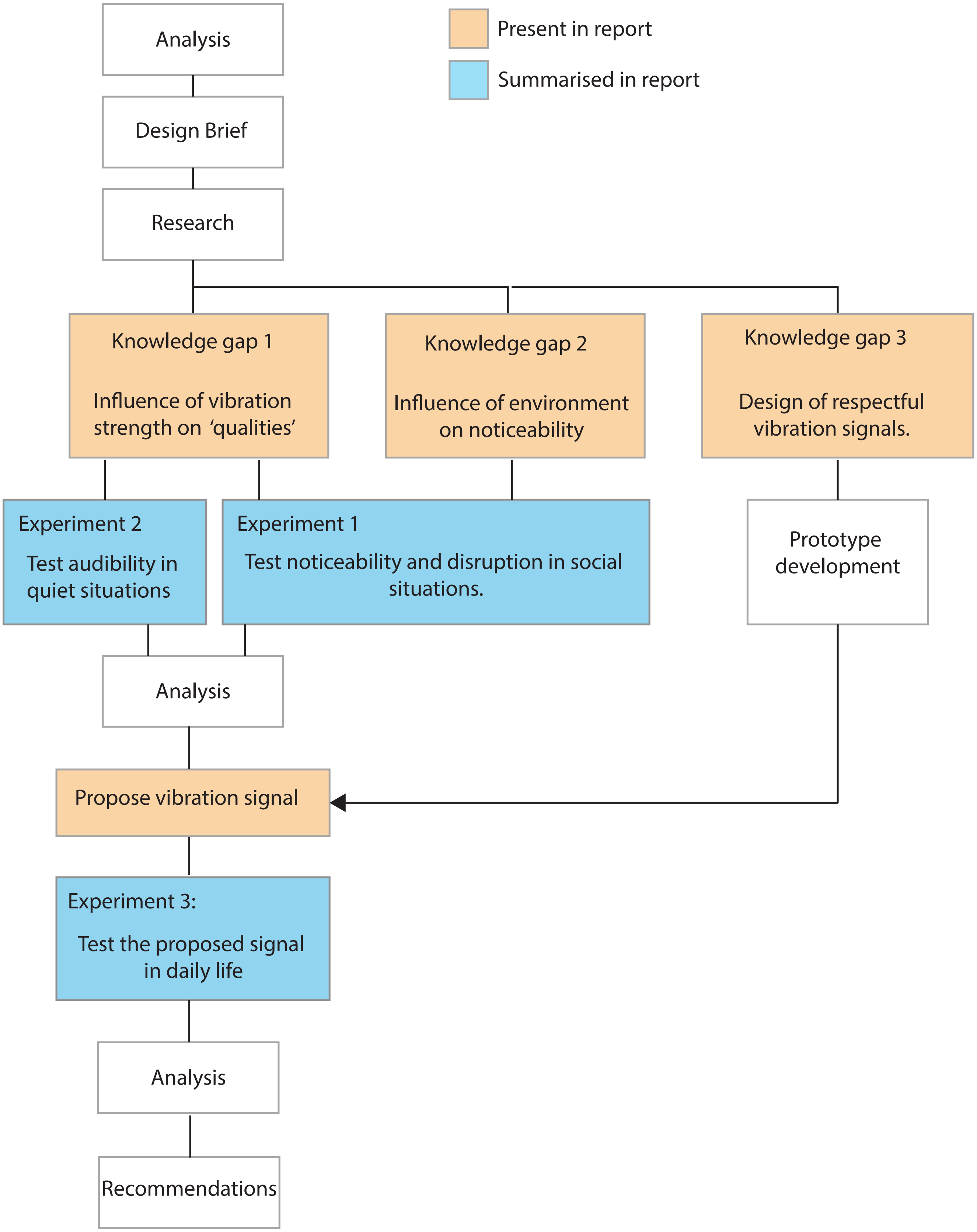

Figure 4: Project structure

Section 2: Background

2.1 Previous work

In 2017 Matthijs Vollebrecht wrote a master thesis about supporting veterans with Post Traumatic Stress Disorder using a smart wearable system. (Vollebrecht, 2017) Vollebrecht fleshed out the problem and suggested a breathing regulating device which veterans could use to get less stressed. See Figure 5.

In 2018 Xinjie Zhang continued in his thesis titled: ”Developing and testing a Smart Wearable System for Sensing Stress of Veterans of PTSD.” (Zhang, 2018) Xinjie created and tested a wearable vest prototype and gave insight into testing stress in the user. Figure 6.

In 2019 Felix Quadvlieg wrote his master thesis titled “Privacy-Driven Interaction Design” about developing a glove prototype to be able to communicate discreetly with users. (Quadvlieg, 2019) This is the concept that Grippy was based upon. Figure 7.

In late 2019 Xueliang Li, who was involved in the project from the beginning, had seven university students test the Grippy prototype. The experiment focussed on high-level aspects of interacting with Grippy. Such as whether Grippy helped increase the participants’ stress awareness and confidence. In addition, Xueliang explored how wearables as ‘partners’ could aid wearables help users. This is very relevant to this study and will be discussed more comprehensively in the next chapter.

The ‘in the moment’ interaction between the glove and the participant was not recorded in Xueliang’s study and is a key part of this research.

Smart wearable system
to support veterans with
Post Traumatic Stress Disorder

Master thesis

Matthijs Vollebregt

Figure 5: Front page of Vollebrechts thesis

TECARE

Developing and testing a Smart Wearable
System for Sensing Stress of Veterans with PTSD

Figure 6: Front page of Zhangs thesis

PRIVACY-DRIVEN
INTERACTION
DESIGN

Creating Transparent Characters
for Smart Objects

Figure 7: Front page of Quadvliegs thesis

2.2 Grippy Project Challenges

Grippy refers to the design and prototyping part of a larger project titled “Things that help out”. The aim is to help people cope with daily stress. Daily stress can manifest itself in anger, agitation or anxiety, through the fight or flight response and is often the cause of an event triggered by a trauma.

Patients know how to deal with their anger, agitation and anxiety, but become aware of the stress they are experiencing too late. “[A veteran suffering from PTSD] ... expressed his desire that someone could remind or even stop him when he was about to lose control.” (Li et al, 2020,)

Warning the user during the onset of stress, also called a just-in-time intervention, using the Grippy glove is promising and some research has been done on the topic. Figure 8 shows a visualisation on how an intervention could help by prompting the user to cope stressors before he reaches the point of no return.

The challenges to the just-in-time interventions can be split into technological challenges and social challenges. This research will mainly focus on the latter.

Most research on just-in-time interventions aims to tackle the technological challenges involved. The two largest technological challenges are predicting the onset of stress in the user, and predicting the type of situation the user is in.

Social challenges involve how and when the user will use Grippy. For example: Whether the user will wear Grippy on his daily routine, or how he or she will act after receiving a signal.

By comparing Grippy to the qualities identified by Li et al (2020), which will be discussed in the next chapter, we determine the knowledge gaps which are discussed in chapter 2.4.

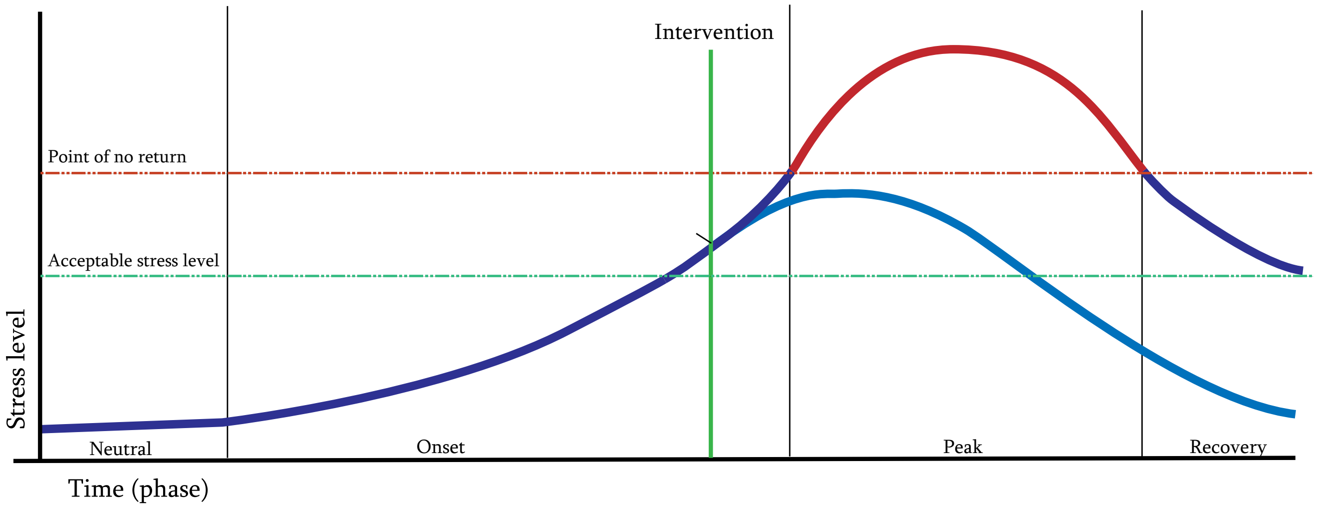

Figure 8: Visualisation of intervention during the onset of stress

2.3 Wearables as partners

One problem that could arise when using vibration signals to send intervention stress alerts to the user, is that the intervention could contribute to the stress level of the user.

For the interventions to not evoke stress in the user, the user needs to create a positive relationship with the wearable. Most people will recognise that they do not have a healthy relationship with their alarm clock for example. The wearable should be seen as a partner rather than a teacher.

Li et al. (2020) laid out three qualities which wearable partners should possess. These are trustworthiness, discreetness, and respectfulness. I have translated the three qualities to apply to the vibration signal specifically. The qualities of the partners are a result of all the various components of the wearable together.

Trustworthiness

To help users change their behaviour 'in the moment', the vibration signal needs to interrupt the user's train of thought. At that point, the users need to trust Grippy enough to question their senses. Users need to trust the wearable to make the right decision. For that, the Grippy signal needs to be accurate.

Additionally, users need to trust that they will receive a signal when they need it. In the situation where the user is not confident that they will notice the Grippy signal, they will not be able to expose themselves as freely as is intended. The user might constantly be busy checking if an alert is going off, or the user might not go to places where they expect to be quite distracted. For this, the Grippy signal needs to be always noticeable.

For this thesis, we will focus on the noticeability of the signal as intervention accuracy is already a topic that is widely researched, as discussed in the previous chapter.

Discreetness

Many people suffering from both physical and physiological ailments describe the stigma of being a patient. It is widely accepted that most people want to keep their ailments private. The interaction with the wearable device thus should only be obvious for those in the know.

The intervention signal on the other hand contains very personal information. If the people around the user know that the user is suffering from daily stress, the fact that the user is currently getting stressed might greatly influence the relationship. You could for example imagine a heated discussion between two people at the dinner table where Grippy's intervention signal is audible. I can imagine that the other party would not ignore hearing this signal and not let the Grippy user deescalate the situation himself.

Therefore, the vibration signals sent by Grippy need to not be audible by other people around the user.

Figure 9: Grippy prototype being worn while the user gives a thumbs up

Respectfulness

Users have different personal values they find important. Considering 'withdrawing from a conflict' weak, trust in principles and authority, and upholding personal privacy are examples of this described by Li et al. (2020). Grippy's interaction with the user must be respectful of these values.

We can see respecting personal values come into play when the user loses autonomy. An alert signal will not be directly disrespectful of ones personal values, but how the user thinks he is expected to respond to the signal might. Because Grippy needs to map how the user is doing, the user is expected to respond to Grippy's signals. Thus, how and when the user is expected to interact with Grippy needs to account for the user's personal values.

The solution to this is twofold: First, the severity and urgency of Grippy's alerts should be clear to the user to allow the user to make informed decisions between his personal values and Grippy's signal. Second, the user should not be inhibited in his actions until he means to receive information from Grippy. We call this inhibition in the user actions disruption. For this, a balance needs to be found between making sure to grab the attention of the user and the signal not being too disruptive.

2.4 Knowledge Gaps

Three related research gaps need to be discussed regarding the design of vibration signals. These research gaps come from my understanding of the current state of the subject, and the challenges I perceive.

The qualities of partners which are described in the previous chapter, trustworthiness, discreetness and respectfulness have yet to be applied in vibration signal design.

We have quite concrete ideas of how to create a trustworthy and discreet vibration signal. We can build trust by creating an accurate signal that is always noticed and we can have discreetness as long as the signal is not audible to other people. However, how these two relate in terms of required vibration strength, how vibration noticeability is affected by environmental factors, and how vibration signals can be made more respectful is not yet fully understood.

2.4.1 The relation between vibration strength, noticeability, audibility and disruption.

The vibration strength thresholds at which Grippy's vibration signal becomes noticeable, audible and disruptive are poorly understood. Figure 10 shows a visualisation of what the thresholds might be. Here, area A shows the appropriate vibration strength of the vibration signal. It could be possible that at low vibration strength, a vibration signal might be disruptive to the user before it becomes audible, which would result in area A. At high distraction levels, the vibration signal might be audible earlier than the vibration is noticeable. This would correspond to area C in the picture. In this case, vibration strength would not be a discreet way of alerting the user in relatively quiet but stressful environments such as tests. Area A and C are hypothetical and might not exist.

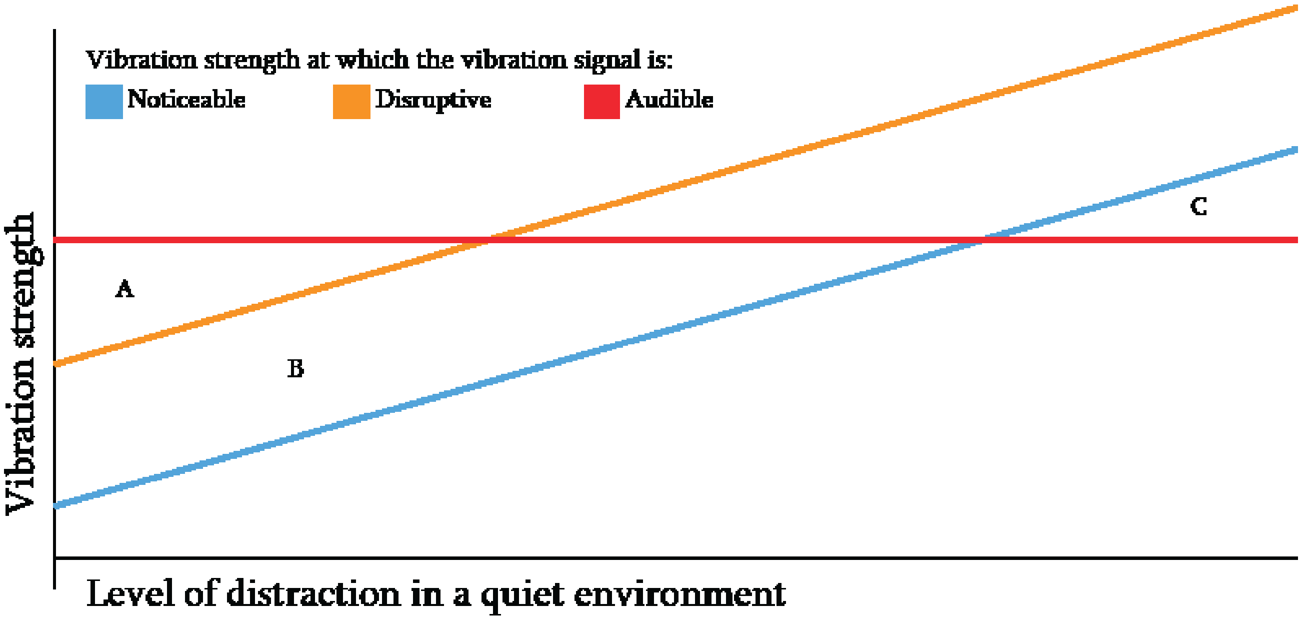

Figure 10: Visualisation of possible vibration strength impact on noticeability, disruption and audibility.
With: A: Area where audibility alone is not an appropriate upper threshold on vibration strength.
B: Area in which the vibration strength is appropriate.
C: Area where vibration signals are not a discreet way of alerting the user.

We use the word ‘just-noticeable’ to describe vibration signals which are on the edge of noticeability, or rather, are not disruptive. Just-noticeable vibration signals are deemed necessary to achieve discreet and unobtrusive vibration signals.

There is various research on the noticeability of vibration signals, especially when comparing between various modes of signals, such as sound, vibration, light, warmth and pressure. In various scenarios, vibration signals are highly noticeable in comparison to other types of signals. However, in these comparisons, the strength of the vibration motor is often not limited by the noise created by the vibration motor.

2.4.2 Which influence environmental factors have on vibration noticeability

One of the problems that arise when we are trying to adapt vibration strength to send a just-noticeable vibration signal, is that we do not know which factors influence the user’s ability to notice vibration signals. To the best of my ability, I found limited resources describing this.

While there is some research on how vibration noticeability is influenced by physical activity, there is little information on how other environmental distractions influence vibration signals. Mapping these distractors becomes more relevant when we look at just-noticeable vibration signals.

2.4.3 How to design respectful stress alerts

As described in the previous chapter, respectful stress alerts should tell the user situation-specific information while not disrupting the user. To convey information, it is likely that signal patterns are required, as Sonneveld and Schifferstein (2008) mention that people cannot tell detailed information from vibrations on the skin. However, the stress alert intervention might be, by nature, disruptive to the user. Zheng and Morrel (2012) found that signals which were experienced negatively, were better able to capture the user’s attention.

Additional insights are needed into how to design vibration signals that can be accurately discerned from one another, while not Disrupting the user.

2.5 Grippy Prototype

The goals and broader functionality of Grippy are introduced in chapter 1.2.1. This chapter will focus on the Grippy prototype. First, an explanation of Grippy will be given followed by the distinction between the two ways of wearing the prototype.

2.5.1 Overview

The Grippy prototype consists of a Physical glove and a phone application. The phone application can communicate with the physical glove over BlueTooth. During daily stress, the researcher will mainly interact with the Grippy glove and the interaction with the Grippy glove is what this report explores. The phone application is used to send commands to the physical glove and to store sensor data. On the next page, an annotated picture of Grippy can be seen in Figure 11.

[1] Vibration motor

The Grippy glove can send preset vibration signals at various intensities. By repeating these vibration signals we can create continuous vibration signals or vibration patterns to the user.

[2] Pressure sensor

The user can interact with the glove by clenching the pressure sensor in the hand palm. Normally this is used by the user of Grippy to convey his stress level by pressing hard or soft. During the first experiment, this pressure sensor was used by participants to repeat patterns sent by the vibration motor. In the second and third experiment, the pressure sensor was not used.

[3] Phone application

The phone application is used to send commands to the Grippy glove. The displayed buttons changed to the requirements of the experiments. The phone application also logs the data on the background so that it can be analysed in a spreadsheet at a later date.

[4] Challenge button

This button located on the back of Grippy is originally used to tell Grippy that the user wants to go on a challenge. This was not relevant to this project and as such, it was not used. The button functionality replaces the pressure sensor functionality in the 3rd experiment where the pressure sensor is folded away as discussed in chapter 2.5.2.

[5] Electronics housing

The batteries and circuit required for the Grippy glove to work are all contained in this housing.

[6] Sensors

The glove contains various sensors which are useful for Grippy’s intended functionality. These are an accelerometer to measure steps and a heart-rate sensor to measure heart-rate levels. These were not used. Unfortunately, the heart-rate sensor was not accurate enough for the experiments and there was no need to use the accelerometer.

2.5.2 Vibration motor

A LRA 2 VAC vibration motor with a resonating frequency of 235 hz and 1.4G of vibration force was used during all three experiments. (Part nr: G0832022D) The Adafruit DRV2605 Haptic Controller was used to control the strength, patterns and wavelength of the vibration signals. The vibration motor is located on the back of the wrist and is embedded in the prototype material.

Two vibration signal strengths are discussed in this report. The low strength signal and the high strength signal. The high strength signal refers to a ‘buzz’ like signal at 100% of maximum vibration strength. The low strength signal refers to a ‘buzz’ like signal at 40% of maximum vibration strength. These are Adafruit DRV2605 presets 47 and 50 respectively. It is unknown what the vibration force and resonating frequency of the low strength signal are, however, when testing on myself, the experienced vibration intensity appears to increase linearly with the indicated percentage values.

Figure 11: Grippy prototype breakdown

Figure 12: Wearing 'Full Grippy' outside

Figure 13: Wearing 'Wrist Grippy' outside

2.5.2 Wearing Grippy

During the experiment, Grippy has been worn in two ways. 'Full Grippy' and 'Wrist Grippy'. Both of wich can been seen in Figure 12 and 13 respectively. The difference is that the pressure sensor is tucked away in 'Wrist Grippy'. This frees up the hand which allows the user to hold items without sending false positives. 'Wrist Grippy' was used during the third experiment. We used Full Grippy during the first two tests with participants.

Section 3: Study 1

Noticing Grippy

3.1 Introduction

This experiment aims to find out at what vibration strength Grippy can be noticed in social environments. This is relevant for finding the just-noticeable vibration strength discussed in the first knowledge gap. Social environments were chosen because interpersonal encounters are known to be cause for daily stress and the proximity of other people is required for the vibration signal to be not discreet.. There are three sub research questions.

What is the weakest vibration signal that is still noticeable in each social activity?

To be able to send a 'just-in-time' stress alert to the user, we have to be sure that the user will notice the signals when they come in. We expect the noticeability of vibration signals depend on the situation the user is in, and therefore the just-noticeable vibration strength might differ per situation. Knowing this lower threshold will allow us to send just-noticeable vibration signals in addition to giving insight into whether adaptable vibration strength is needed.

How does social activity influence vibration signal noticeability and response?

Social situations are assumed to be relevant for appropriate vibration signals for three reasons. First, stressful situations evoke a similar physical response as daily stressors. Second, daily stressors often involve other people and third, the presence of other people in an otherwise quiet environment increases introduces the possibility of other people noticing the signal.

By understanding how social situations influence the user's response to vibrations signals we might gain insights into what the qualities of this interaction should be. Relevant factors in social situations are whether people are talking, how focussed the user has to be to partake in the activity and how easy it is for the user to not be focussed on the activity.

At what point does the vibration signal become uncomfortable to the user?

While the comfort of the user does not influence just-noticeable vibration signals. The point at which the vibration signal becomes uncomfortable represents an upper threshold for the appropriate vibration strength. However, with the prevalence of clearly audible vibration signals in mobile phones and fitness trackers that are already in use, this is unlikely to be the case.

3.2 Method

At the time of this experiment, experiments which included physical contact between the participant and the researcher would not be approved due to the COVID-19 pandemic. To ease setting up each participant with the prototype, roommates of the researcher were used as test subjects. Fourteen dutch students from the Delft University of Technology, ranging from 18 to 26 years in age participated in the experiment. Each participant was seated behind a desk in his or her room and was invited to a video call. This video call includes the researcher and two actors not part of the roommates. As all participants know each other well, actors from outside are used to evoke social stress. The actors will interact with the participants during social tasks. This way, the researcher can focus on time- and note keeping.

The Trier Social Stress Test (Kirschbaum et al, 1993), TSST in short, is widely used to evoke stress in the participants. The goals of the TSST and this experiment overlap on the need to evoke social stress. However, the TSST focuses solely on evoking stress in the participant, while in this experiment we are interested in the effects of ‘stressful’ social situations. Taking inspiration from the TSST, the actors will be introduced as “judges who evaluate the participants’ performance.”

The participant will have two tasks. First, the participant will be placed in social situations such as small-talk and listening. The participant is then asked to repeat vibration signals during those situations to test the noticeability of the vibration signals. The next two subchapters will describe the social tasks and the vibration signals in more detail.

3.2.2 Social tasks

The social tasks the participants will be exposed to should represent various social interactions people might encounter in daily life. Situations in which the user is stressed are more interesting as the user will also be stressed at the time of an 'intervention' by Grippy.

The tasks should last for a minimum of two minutes and have unique characteristics. Four tasks were selected in addition to a baseline test.

1: Baseline:
In this situation, the participant is asked to do nothing for two minutes and just focus on repeating the patterns.

2: Listening:
When listening, the participant is hearing audio and has to keep focussed to follow the story. The participant does not have to formulate sentences during this experiment.

3: Small-Talk:
During the small talk, the user has to both listen to another person and formulate sentences.

4: Presentation:
During the presentation, only the user is talking. He or she has to formulate sentences. Presentations are also widely regarded as stressful.

5: Puzzle-solving:
Puzzle-solving is not a social situation. This situation is included to be able to differentiate distraction from the presence of audio and cognitive load. During puzzle solving there is no audio cue, but the user does have to think. If the cognitive load has a strong influence on signal noticeability, we expect it to see it here.

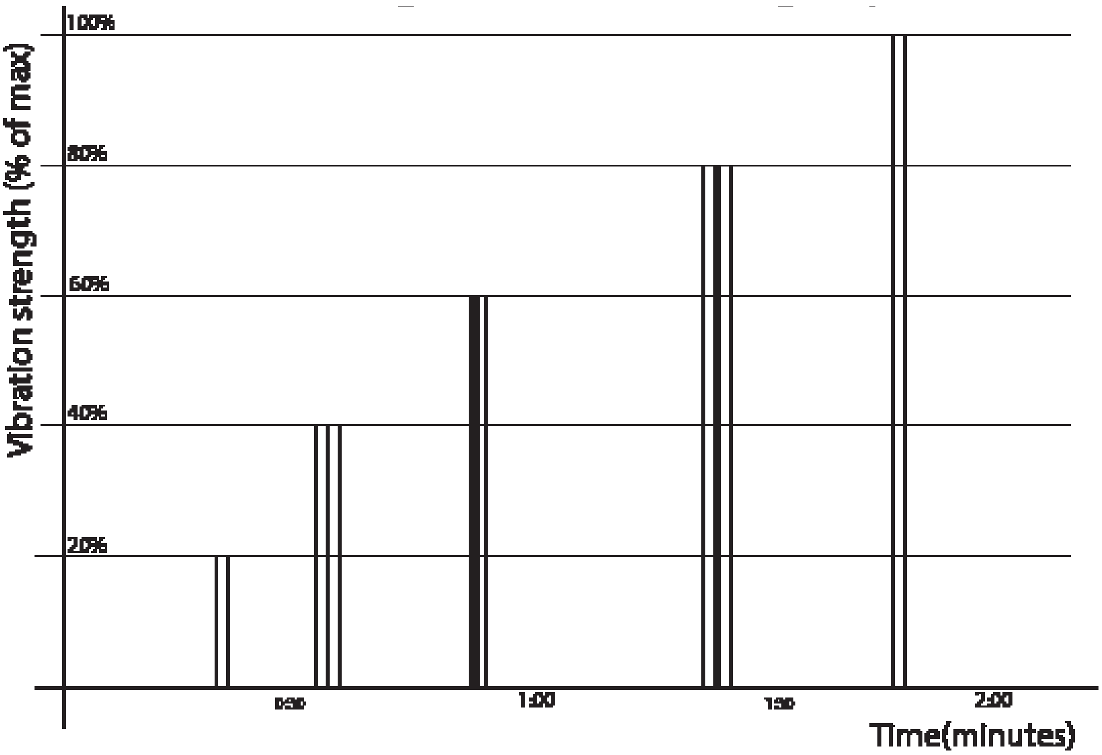

Figure 14: Visualisation of vibration strength during sequence.

3.2.3 Noticing vibration signals

By having the participants repeat to vibration signals by repeating the pattern we can record whether the users notice the vibration signals. The user can send signals using the pressure pad located on the palm of the glove. The following five patterns are chosen as they were assumed to be easy to distinguish and repeat by the user.

Patterns: (X means on, 0 means of)

A: [X,0,0,X,X,X,0]
B: [X,0,X,0,X,0,X]
C: [X,0,0,X,0,0,X]
D: [X,X,0,0,X,X,0]
E: [X,X,X,X,X,0,0]

Preset vibration signal sequences will be used to send vibration signals at preset intervals. The participant must not know when the vibration signals will happen, and the researcher will not be close enough to send manual vibration signals to the participant. The pre-set intervals between the signals will be randomly generated and thus unknown to the participants.

In each signal sequence, the android app will send five signals at preset intervals to the glove, each representing a vibration pattern and intensity. The intervals between the signals are chosen randomly but individual signal sequences are the same for each participant.

The vibration strength will go up in increments of 20% from 20% to 100% during each signal sequence. A visual representation of this can be seen in Figure 14.

The signal sequences will be started through the grippy phone application. There will be five signal sequences in total. One for each task and one for the baseline measurement. The participant is requested to start a signal sequence at the start of each task as directed by the researcher.

The Grippy application home screen will show a button each signal sequence as can be seen on the phone in Figure 15. These buttons are labelled A-E and should be pressed alphabetically. The researcher will also call out which button needs to be pressed. Lastly, the buttons will be disabled once pressed. This way the participant does not accidentally follow the same signal sequence twice.

3.2.4 Additional measurements

Heart Rate

The participant's heart rate will be measured with a Mio Fuse band. Timestamps can be used to match the heart-rate data to the signal sequences. This way the participant's heart rate can be compared even though the lengths of individual tests can vary. This data can be used to see whether the social tasks evoked a heart-rate response in the users.

Qualitative insights

The qualitative insights will be gathered in two ways. Short interviews are held at the end of each signal sequence asking for elaboration on what happened and how difficult the user thought the task was.

Then, after the experiment, the researcher will explain more about Grippy and a more open-ended interview will be held about the merits and demerits of Grippy.

Qualitative insights are required from the participants for two reasons. First, to get a full picture of what is going on, it is valuable to get the participants own insight on the cause of missed or incorrectly repeated signals. Second, since we are already talking to the participants, we want to know what they think of Grippy. The aspects that the participants as a group like or dislike are more generalisable than just the researcher introspection.

Figure 15: Items that are provided to the participants during the first experiment.

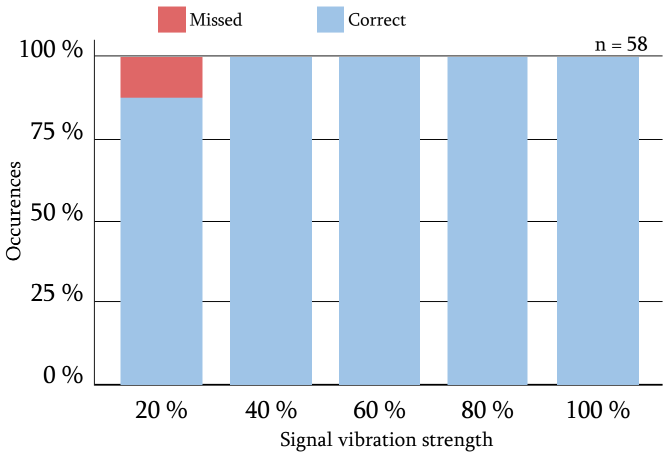

Figure 16: Missed signals versus vibration strength.

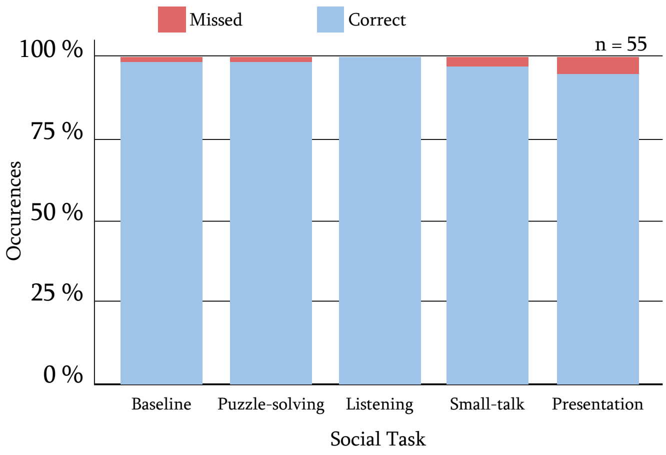

Figure 17: Missed signals versus task.

3.3 Results

3.3.1 Missed signals

Vibration strength

We expect the missed signals to go down as the vibration strength increases which is indeed what we see. However, the 20% strength vibration signal was the only signal which was missed by the participants. As can be seen in Figure 16. Two participants reported that they did notice this signal but forgot or were unable to respond. In this experiment the signal was denoted as noticed when the participants responded to the signal.

The hypothesis was that there would be a threshold at which the vibration signal would always be noticed by the participants. The data indicates that this threshold lies at 40% of the maximum vibration strength.

Social task

When looking at how the situations influenced the missed signals, see Figure 17, we see slightly more signals being missed during the presentation and puzzle-solving. However, we also get a missed signal during both the listening and the baseline experiment. It could be that the 20% vibration signal is missed because of environmental distractions rather than the situation in which the user is present.

One participant mentioned feeling that the last signal during the presentation felt the faintest. This might be an indication that stress or cognitive load do influence the noticeability of vibration signals.

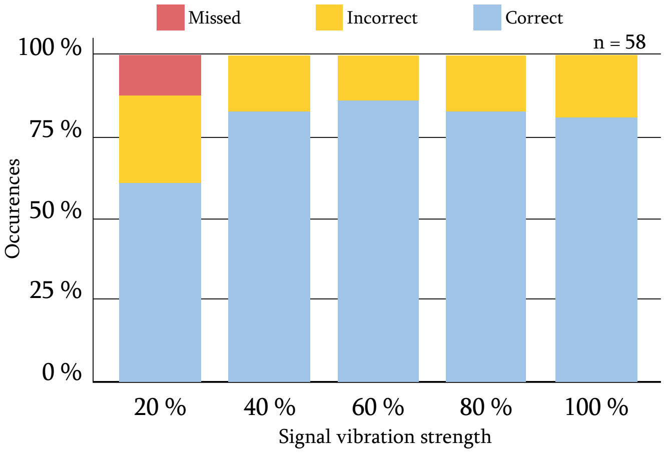

Figure 18: Vibration accuracy versus vibration strength.

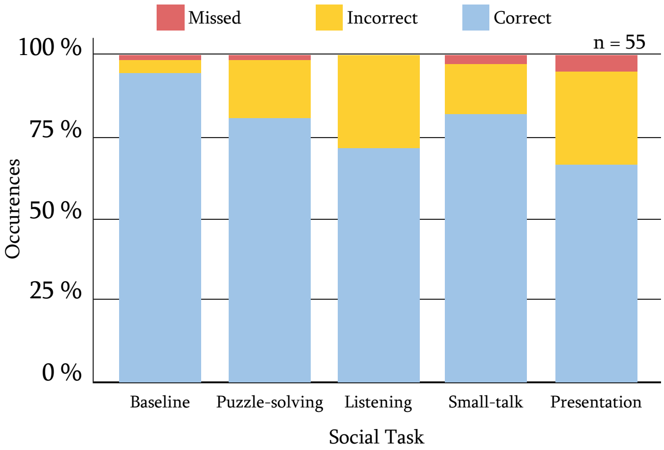

Figure 19: Response accuracy versus task.

3.3.2 Signal response accuracy

Vibration strength

The participants were asked to repeat a signal pattern consisting of one, two, three or four buzzes. If the participant did not match the number of buzzes of the original pattern the response was tagged as incorrect.

The amount of inaccurate signal responses is highest at the softest vibration signal at 20% of the maximum vibration strength. This can be seen in Figure 18. And is constant from 40% to 100% maximum vibration strength. This seems to hint at a ceiling effect on the influence of vibration strength on the noticeability of the vibration signal.

Social task

We see quite a strong influence of situation on pattern repetition. See Figure 19. During the baseline, we see an above 90% signal repetition accuracy. Which drops to around 80% during listening and puzzle-solving and 70% during small-talk and presentation.

When looking at individual situations, we see that the 20% strength signal response accuracy is significantly lower than those at higher vibration strength. Except for the puzzle-solving exercise where the total of missed and incorrect signals is more in line with the incorrect signals at higher vibration strength.

One hypothesis was that if a participant notices a signal at a certain vibration strength level, he will also notice signals at a higher level of vibration strength. This turned out to be true, as only signals at the lowest vibration strength were missed.

3.3.3 Influence of social situation

There are three factors in social situations which are likely to influence the noticeability of the vibration signals. First, the sound level in the room, or rather whether people are talking. Second, how focussed the user has to be to partake in the activity and third, how easy it is for the user to not be focussed on the activity, either because the expected focus is low or whether the user is focussed can not be checked.

I view cognitive load as the result from the combination of the focus required to perform the task combined with the willingness of the user to perform the task.

Vocal vs Non-Vocal

We see that the response accuracy is significantly higher during puzzle-solving than during the listening, small-talk and presentation tasks. This might indicate an effect of sound on vibration noticeability. If this were the case, that could mean that noise can distract from vibration signals. However, the puzzle-solving accuracy results show a dip around the 60% vibration strength mark, indicating that there is a lot of variance in the results. Also, presentation and small talk both have additional social pressure, and as such participants might have been more inclined to drop focus on the task during the puzzle-solving compared to the more social tasks.

Cognitive load

Cognitive load was a large influence on the ability of users to respond to vibration signals. However, this was not limited to just the puzzle-solving task. Participant 11 talked about the difficulty of responding to signals which arrive during a sentence compared to signals which arrive just after. Participants 2,4, 5,7,8 and 11 also mentioned this effect when they were holding information during the puzzle-solving. Either mentioning having to re-read the puzzle or having difficulty responding to the pattern during the puzzle.

This mainly had to do with responding to the signal and not noticing the signal. By their own account, the participant had to focus some of their attention to count and store the number of vibrations they heard. Trying to extract this and remember it while also formulating a sentence or remembering something else was difficult. Most participants reported dropping focus on the task at the moment a signal hit.

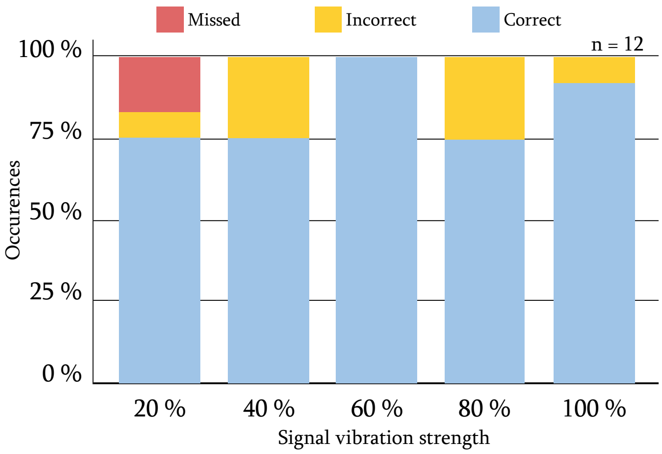

Figure 20: Accuracy versus strength during puzzle.

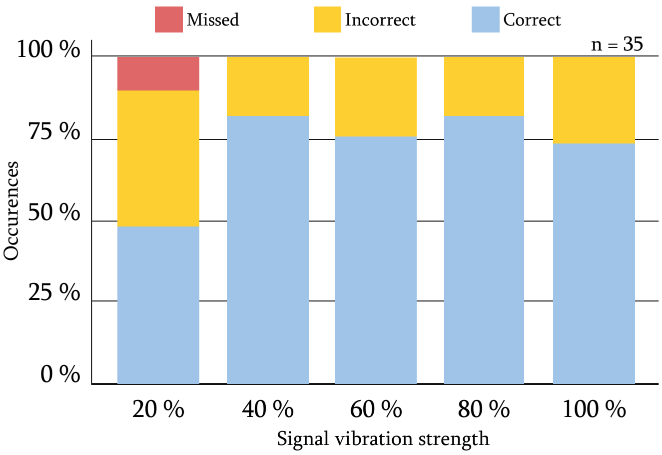

Figure 21: Accuracy versus strength during vocal.

The focus of the users put on the activities greatly influenced the difficulty they experienced responding to the signal. Participant 7 was known to be good at puzzles and felt like he had something to prove. He mentioned that the puzzle-solving was the hardest task to combine with responding to vibrations while having small-talk was the easiest. Participant 6 experienced the exact opposite, finding small-talk to be the hardest task to combine and puzzle-solving the easiest. With the reasoning that because you have more control during puzzle-solving, it is easier to pause.

Stress

Participant's heart-rate response is an indication of induced stress in the user. In Figures 20 and 21, you can see the average heart-rate of the users throughout various scenarios.

We see a drop in the heart-rate during the start of the baseline test where the participant is asked to sit calmly. Figure 22. We see that this slowly rises throughout the tests. The heart-rate of the participants seems to constantly be around 75 beats per minute at the start of each social task and slowly rises throughout the tasks.

Before the presentation, the participants are given time to prepare. We can see the heart-rate of the users rise during the preparation.

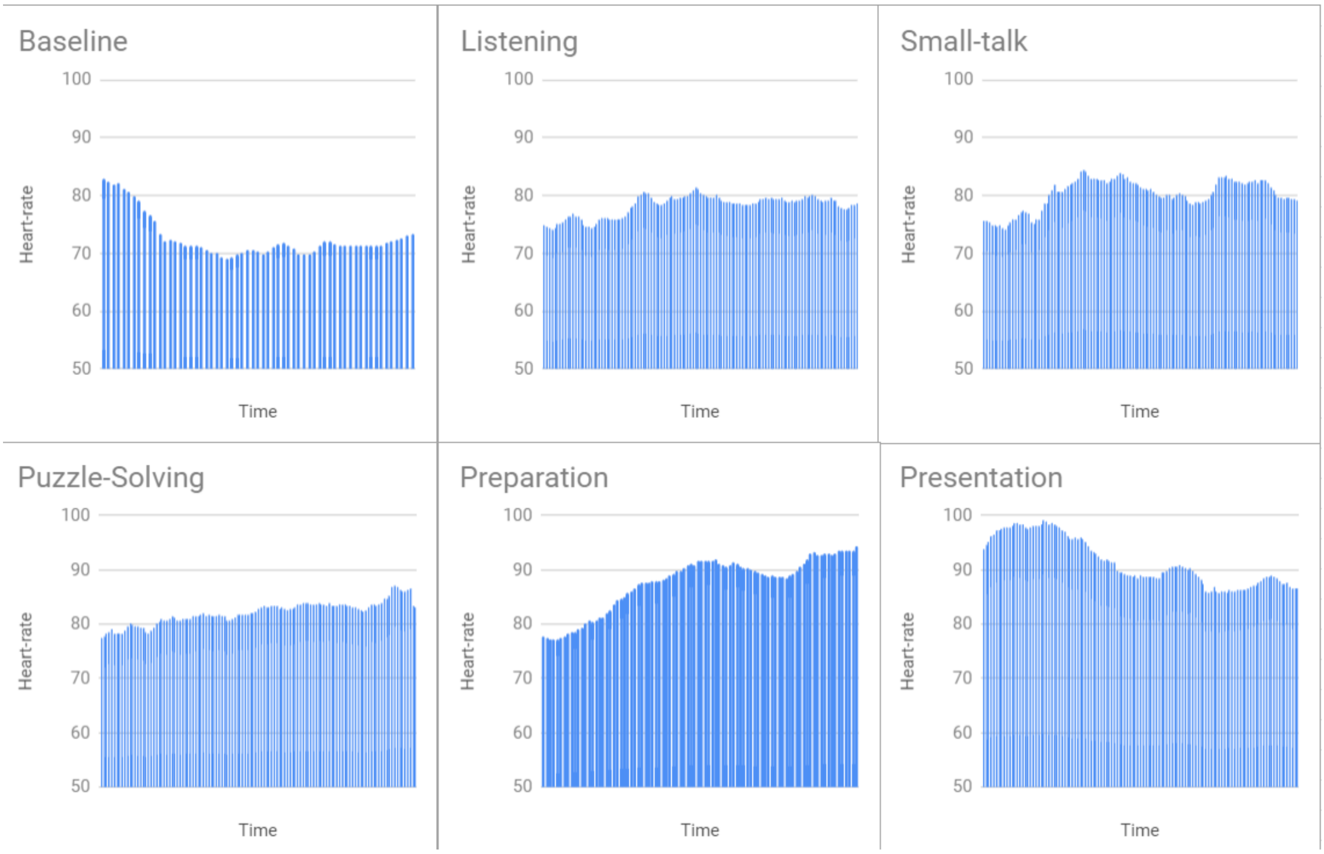

Figure 22: Visualisation of heart-rate over task duration (2 - 4 minutes.)

3.3.4 Qualities of the vibration signals

In the previous subchapters I discussed the noticeability of, and users ability to respond to, the vibration signals in the moment. In this subchapter we discuss how the other qualities of the vibration signals were experienced.

Signals were not memorable

After each routine, the participants were asked how many vibration patterns they had felt. Most participants guessed around the five patterns on average. Though some believed to have felt only 2 or 3 at times while correctly having responded to all the signals. At the lowest vibration strength, three participants mentioned only realising a vibration had happened when it already passed. This could indicate that these signals are not memorable experiences and such an alert on itself might be easily forgotten.

Low influence of vibration strength on experience

None of the participants mentioned physical discomfort from any of the vibration signals. Most participants did not even notice that the vibration signals had varying strength. Half of the participants noticed that the first signal was noticeably weaker, and only a single participant picked up on the fact that the signals got stronger over time. The idea that it is difficult to notice qualities of vibration signals is supported among others by Sonneveld & Schifferstein (2008).

This might also indicate that the strength of the vibration signal does not influence the disruption caused by the vibration signal. However, in this experiment the vibration only happens momentarily, the influence of vibration strength on disruption is likely higher with a continuous vibration signal.

3.3.5 Participant insights related to Grippy

The interaction with Grippy was experienced as positive. Being able to discreetly use the pressure sensor to send information was appealing. The participants were not overwhelmingly enthusiastic about using Grippy. Participants mentioned that they would at least give it a try if they suffered from panic attacks or a doctor recommended it to them. The two biggest reasons why people wouldn't use Grippy are 'being constantly reminded you suffer from stress' and 'the electronics box being too big.' The reason why people would use Grippy is that Grippy would know more than they do themselves.

3.4 Discussion

At 40% of maximum vibration strength, the vibration signal was noticeable to each participant in each social situation. This will be the low strength signal that will be tested in further experiments. The social situations greatly influence the participant's ability to correctly repeat the received vibration signal patterns. The participants having to mentally focus on both remembering the pattern and the task is likely the largest cause for this effect. The vibration signals did not become uncomfortable to the user.

The heart-rate data indicated that the tasks were able to create stress in the user. The vibration signals were noticeable in all situations at low vibration strengths, this indicates that stress might not be a prohibitive factor in vibration signal noticeability.

The qualitative interviews revealed that focus and cognitive load could have a larger influence on the user's ability to repeat the vibration signal patterns. This will likely also be the case during a 'conversation' between Grippy and the user. This tells us a solution is necessary which allows the user to understand the signals being sent without the user having to stop his or her train of thought in the middle of a sentence.

During the development of the experiment, little time was spent testing the effect of the pattern sequence on the response accuracy. The rationale behind this is that when the pattern sequence starts having an influence, the participant already noticed the signal. However, some patterns could be harder to repeat than others, which would influence the response accuracy.

Many aspects such as physical activity, hand movement and environmental distractors, were not tested and also not taken into account in this experiment. To see what other aspects influence vibration noticeability, Grippy needs to be tested in more varied situations.

Section 4: Study 2

Hearing Grippy

Figure 23: Experiment 2 setup

4.1 Introduction

This experiment aims to find out at what vibration strength bystanders can hear Grippy in a quiet environment. This will provide an upper threshold on the appropriate vibration strength as an audible signal will not be discrete. If the vibration signal is audible in quiet situations before it is noticeable in stressful situations, vibration signals are unable to discreetly alert the user. A quiet environment was chosen because the results will be representative of all situations.

In addition to the main research question, this experiment aims to validate the results of the first experiment. We do this by testing whether it is possible that sound influenced the first experiment.

At which intensity is the noise generated by Grippy's vibration motor audible to a person standing next to the user?
The purpose of this experiment is to test at which intensity the noise generated by the vibration motor of Grippy is audible to the user and the people next to him. If the people around the user notice the vibration signal, the signal is not discrete.

Could vibration noise be a contributing factor in the audible cues of the first experiment?
If the participants of the first experiment could hear the vibration signal, that could have influenced the results of the first experiment as the sound could contribute to the noticeability of the vibration signals..

4.2 Method

In this experiment, the researcher is wearing Grippy. A signal sequence of 5 patterns is sent to the glove. Each pattern will be identical except for the vibration strength. The vibration strength of the pattern will increase from 20% maximum vibration strength to 100% vibration strength in intervals with step size of 20%. The participant, who is located next to the researcher, will then call out when he hears the vibration.

It is important to take distance into account when testing for audibility. A person who puts his ear right next to Grippy will hear even the faintest vibration signals. It is assumed that 50cm is a sufficient distance as strangers will generally respect each other's personal personal boundaries.

For the experiment, a relatively silent room is needed. It is unlikely that a participant finds himself in a completely silent environment during daily life. Therefore a bedroom with closed doors and windows was chosen. The light buzzing of the laptop fan was the loudest in the room, with exceptions of occasional cars passing by outside.

A simple single note signal pattern was chosen. The intervals between the vibration signals ranged between seven and fifteen seconds. The participants did not receive an example of this buzz and were asked to respond to unfamiliar or unexpected sounds.

When the participant notices a signal he or she will say it out loud. The researcher will then note a ‘lap time’ with a stopwatch. These ‘lap times’ represent the timestamps at which the participant heard a vibration signal. The researcher is chosen to operate the stopwatch for two reasons: First, the stopwatch and vibration routines need to be started at around the same time, which is easier if they are operated by the same person. Second, this way the participant is not aware of time passing and can not try to use that to guess signals.

If the timestamps recorded during the test happen within five seconds after a signal was sent, the signal is recorded as noticed.

Then the percentage of noticed signals over occurrence for each level of vibration strength can be calculated. By comparing these percentages to the percentage of signals that can be picked up for the signal to no longer be discrete, the vibration strength at which the signal is no longer discreet is a ‘relatively silent’ room can be estimated.

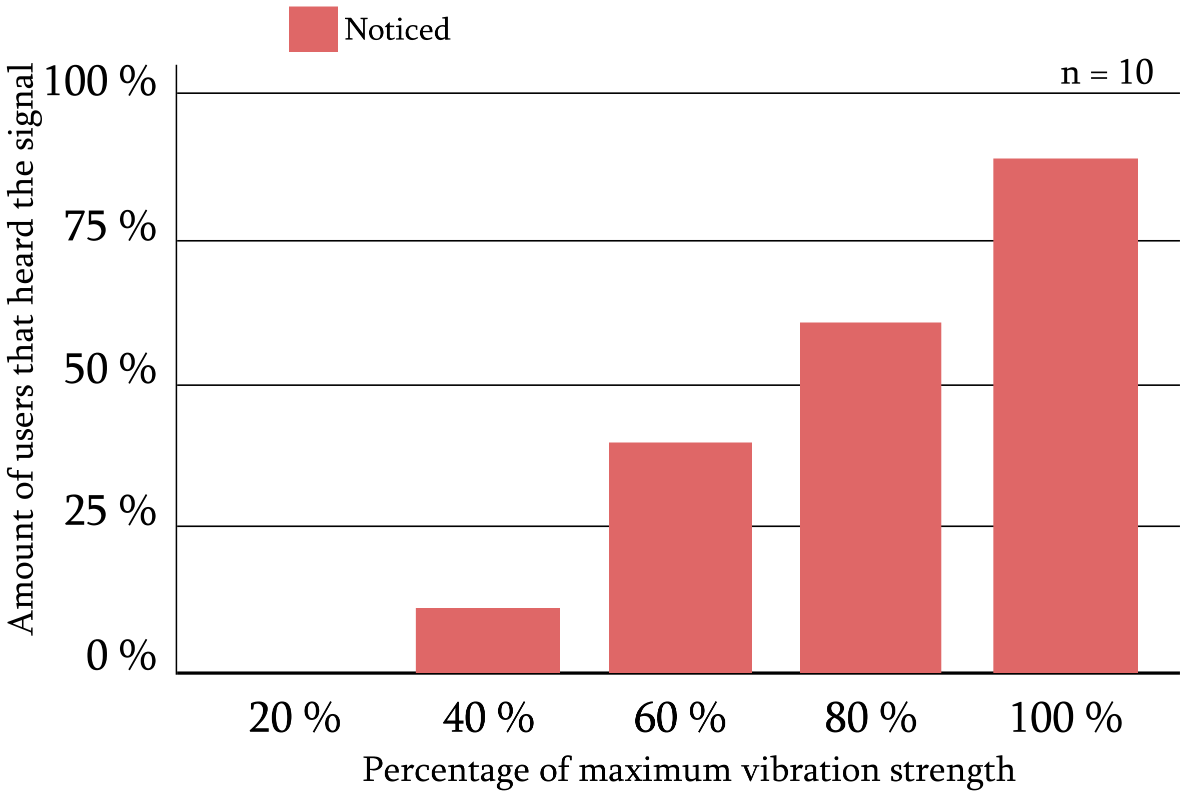

Figure 24: Vibration signal audibility vs vibration strength

4.3 Results

Maximum discreet vibration strength

In a ‘quiet’ room at 50cm distance, the vibration signal is not noticeable at 20% of the maximum vibration strength and only noticed once at 40% of the maximum vibration strength. The participant who noticed the signal at 40% vibration strength mentioned that he would not have heard it if he was not actively listening for it. Therefore, we conclude that the vibration signal at 40% of maximum vibration strength is not audible to passive observers and is the upper threshold of our vibration strength for discreet signals in quiet environments.

Participant’s who noticed the signal at certain vibration strength also noticed all the stronger signals. We also see the noticeability of the vibration signal rise as the vibration strength increases. This indicates that there is no clear threshold at which the vibration becomes audible.

Vibration noise did not influence the first experiment

The moment the vibration motor becomes audible to the user does not overlap with the moment the vibration becomes noticeable. This is a strong indication that vibration noise did not have a major influence on the results of the first experiment.

4.4 Discussion

This experiment demonstrates that the vibration strength required to alert someone who is giving a presentation would still be discreet in a silent room. This indicates that a single non-adaptive vibration strength might be sufficiently noticeable and discreet in most indoors social situations. It is also unlikely that noise has had an influence on the first study and influences the noticeability of the vibration signal.

Whether the vibration motor is audible is strongly reliant on environmental noise. The sound level of the chosen bedroom could also be softer or louder than other rooms people generally experience as quiet. A calibrated decibel measurement could be used to give a more accurate description of the environment. Additionally, the noise level fluctuates because of sounds from cars driving by and people walking upstairs.

Finally, only a single pattern was tested during the test, it could be that signals consisting of multiple shorter pulses could more easily attract the attention of the user. Though, it is unlikely to as the participants were actively listening for the vibration signal.


TUL

Section 5: Study 3

Wearing Grippy

5.1 Introduction

This experiment aims to explore whether a non-adaptive vibration signal could be appropriate and noticeable in daily situations. From the previous knowledge gained regarding noticeability, audibility and disruption a soft continuous vibration signal was developed which will be tested in the experiment. The influence of a wider range of environmental factors will also be tested in this study.

To do this, an autoethnographic study is set up where the researcher will wear Grippy in daily life and respond to vibration signals sent to him at irregular intervals.

To the best of my knowledge, there is not a lot of work on the noticeability of vibration signals in daily life. Likely, because for most vibration signal applications, increased vibration strength is a sufficient solution to this problem.

5.1.1 Proposed non-adaptive vibration signal

A non-adaptive vibration signal that can be used in all situations in the users daily life is preferred over an adaptive signal. The reason for this is that the solution would solve a few large challenges. To create an adaptive signal, the situation the user is in needs to be predicted accurately. Besides the technological hurdles and limited data that is available right now, privacy issues might also come into effect in a later stage.

The first two experiments hint that the low strength vibration signal, as discussed in chapter 3.4. could be both noticeable and appropriate in most daily situations. Additionally, in experiment 1 participants could not focus on both responding to the vibration signal and their train of thought at the same time. This caused inaccurate readings of the vibration signals. Therefore, a continuous non-adaptive vibration signal that uses these insights, will be used and tested during this experiment.

At the moment the researcher needs to be alerted a continuous vibration signal turns on. This signal consists of a 5-second pattern which is repeated continuously at low vibration strength. When the researcher notices the signal, he will turn off the signal by pressing the button on the back of the Grippy glove.

In the first two experiments, we found that at low vibration strength, the vibration signal is both noticeable and discreet in all social situations. The continuous is assumed to allow the user to ignore the signal for a little while and respond when the user finishes his train of thought.

From an experimental design perspective, the continuous signal is also helpful. The continuous signal ensures that every vibration signal is noticed at some point. This allows for reflection on unnoticed vibration signals at the moment the signal becomes noticeable, which increases the richness of the experimental data.

5.1.2 Potential environmental factors

There are five factors which are assumed to influence vibration signal noticeability. Vibration on the wrist, environmental noise, physical activity, cognitive load, and social pressure. These potential environmental factors form the baseline with which the study is set-up. In the method later in this chapter the activities which are assumed to influence vibration noticeability are discussed. Those activities are selected for their relevance to the five factors below.

Vibration on the wrist/ arm movement

Vibration drowns out other vibrations like noise downs other sounds. This is especially relevant to Grippy's signal as appropriate vibration signals will likely be quite weak. We expect vibrations while the user is cycling or sitting in moving vehicles, but also from weather such as wind.

Additionally, it could be possible that small vibrations are dismissed by the user while grabbing or holding items as some vibrations are expected.

Environmental noise

Sounds might distract from vibration signals. During the first test, we noticed that the 20% vibration signal was easiest to notice during the puzzle-solving exercise where there was no sound present. While the signal used in this experiment will be more powerful than the 20% vibration strength of the first study, sounds may also be louder during this experiment.

Physical Activity

An elevated heart-rate influences vibration signal noticeability that would pose problems as the heart-rate of the user will also be elevated when the user is stressed. Physical activity is easy to plan and will also elevate the heart-rate of the user.

Cognitive Load

During the first experiment, we found that cognitive load, or the level of focus on another task, influenced the user's ability to accurately respond to vibration signals. We expect cognitive load might also distract the user from; or make the mind ignore, the vibration signal.

Presence of others

Other people will likely not influence the user's ability to notice Grippy's signals. While we assume that the distractors prevent the user from noticing the signal, social pressure might prevent the user from responding to the signal. Other people are relevant when exploring what factors cause a vibration signal to be experienced negatively. The user might be less willing to respond to the signals when surrounded by acquaintances or strangers. The number of other people might also influence the user's willingness to draw attention to himself.

5.1.3 Research questions

In addition to the two research questions related to the knowledge gaps, we also want to know how much the six proposed factors influence using Grippy in daily life. That brings us to three research questions. These research questions will be discussed in chapter 5.4.1 Discussion.

Is the non-adaptive vibration signal noticeable in all daily situations?
If this vibration signal is noticeable in all daily situations, that would mean that no adaptation is needed to have a vibration signal that is appropriate for all social situations.

How do the six proposed environmental factors influence the interaction with Grippy's vibration signals?
How much the six proposed environmental factors influence the interaction with Grippy's vibration signals is relevant to predict how noticeable vibration signals will be in situations that are not yet tested.

In addition, the proposed environmental factors can be iterated upon based on differences in noticeability that are unexplained and apparent lack of influence of some of the environmental factors.

How disruptive is the used continuous vibration signal?
As described in the third knowledge gap. A disruptive vibration signal that interrupts the user's train of thought is not respectful. A soft but continuous vibration signal was chosen as the user is expected to be able to ignore the signal when finishing his sentences or immediate train of thought. This experiment aims to find out whether this is true in daily life, and if this makes the signal not disruptive.

5.2 Method

In this experiment, the researcher will wear Grippy during various activities in daily life. Grippy will send vibration alerts to the researcher wich the researcher will have to confirm by pressing the button on the back of the Grippy prototype. The accuracy and response times of the researcher's responses will be collected in addition to empirical data on both the environment and response experience. Next to regular daily activities, some activities will be curated to include the potential environmental factors described in the introduction.

5.2.1 Vibration signal

A continuous vibration pattern at the low vibration strength will be sent to the researcher. In order to create a longer signal than the software implementation would allow for, the pattern will alternate between two patterns. Here X is on and 0 is off.

A: [X,X,0,0,X,X,0,0]

B: [X,X,0,X,0,X,0,0]

This pattern was chosen because the rhythm was pleasant. The low vibration strength is the weakest vibration strength that was always noticeable in the first study.

When the researcher reports that he noticed the signal, the signal will turn off. The researcher will report noticing the signal by pressing the button on the back of Grippy. This has been chosen over the pressure sensor in the glove to be able to wear Grippy as a wristband. When worn as a glove the pressure sensor gives false positives while the user is holding items, which occurs quite frequently in daily life.

5.2.2 Activities

We do not need to test in every perceivable scenario. We can assume that if Grippy is noticeable in a scenario with high levels of distraction, Grippy will also be noticeable in scenarios with low levels of distraction. In figure 25, an overview of the curated activities can be found. The relevance of the five potential environmental factors is highlighted for each activity.

Requirements determining the activities:

- The activities need to be part of regular daily life
- The activities together should represent various levels of distraction.
- The activities need to be feasible to achieve considering the Covid-19 pandemic.

Cycling

While cycling, the steering wheel vibrates which is then translated to the wrist. This vibration of the steering wheel might hide the Grippy’s signals.

Working

Mentally switching tasks can be demanding. The vibration signal might not be noticed while formulating a sentence or doing other heavy short-term mental tasks.

Groceries

Doing groceries is a daily situation which includes a bit everything. The user has to think about what he will heat and carry groceries while other people are present and music is playing. The most distracting moments are expected to be: Checking out and having to hurry to find what type of food you are looking for.

Piano playing

The piano is chosen as that is the instrument I can play somewhat proficiently. While playing an instrument, your hands are quite busy. This hand activity might hide the vibration signal. Additionally, the sounds created by the instrument or the focus required to play pieces might also influence the noticeability of the signal.

	Vibration on the wrist/ arm movement	**Environmental noise**	**Physical Activity**	**Cognitive Load**	**Presence of others**
Cycling	**High**	Medium	**High**	Low	Low
Studying	Low	Low	Low	**High**	Low
Groceries	Medium	Medium	Low	Medium	**Medium**
Piano Playing	**High**	High	Low	Low	Low
PC Gaming	Medium	**High**	Low	**High**	Low
Public Transport	**Medium**	Medium	Low	Low	**Medium**
Conversation	Low	Low	Low	Medium	**High**

Figure 25: Table showing the chosen activities with relevant factors highlighted

PC Gaming
PC gaming can mean a lot of things. In this situation specifically we are talking about fast-pased action or racing games where music is playing.

Games which require activity from two hands, fast reactions and quick thinking are a great distraction. Together with listening to music, an immersive action game might distract the user enough to not notice the vibration signal.

Public transport
Vehicles are prone to shake the passengers. This shaking might hide the vibration signal.

Conversation
When having a conversation you are generally expected to keep focus on that conversation, either because you are talking yourself or you are listening to someone else. It is expected that responding to vibration signals while talking might be noticeable to the other person.

5.2.3 Empirical measurements

Researcher Introspection is used to obtain empirical data. Researcher Introspection describes the action of the researcher looking inward to generate scientific data. In these experiments, the researcher is referred to as the researcher-introspector. In Appendix B2 the benefits and weaknesses of this approach are laid out.

An autoethnography is a form of researcher introspection in which empirical findings are described together with the experiences from which they are drawn. This allows the reader to embed themselves in the experiences of the researcher and allows the researcher to more freely report on the insights and hypotheses he obtained.

There are three times at which empirical data will be recorded. Directly after receiving a signal, at the end of the activity, and whenever the researcher-introspector notices something relevant.

For the insights on both the environment and the experience of the vibration signal a digital form is used which is filled in right after the researcher-introspector receives a vibration sigal. The participant should in this moment pause what he or she was doing. At this time recordings are made about the situation the user is in and the experience leading up to and resulting from the received signal. The form with which these comments are recorded can be found in Appendix B5.

After each activity, a short description will be written about the situation. The notes made directly after receiving a signal are more likely to be accurate, in contrast, notes made after the fact put more focus on memorable aspects of the situation and allow for deeper evaluation, due to the lack of time restriction. The description after the activity will likely emphasise moments that are clearly remembered, and thus triggered a stronger reaction.

5.2.4 Quantitative measurements

We consider two types of quantitative data in this experiment, button response time and form response.

The button response time is calculated by subtracting the timestamp at which the signal is send from the timestamp at which the button is pressed. The button response time reflects whether a vibration signal was immediately noticed or was missed. In the case the signal is noticed, the time the user takes to respond can be compared between situations. Because the signals are continuous, and are only send once every 12 minutes on average it is unlikely for a signal to be completely missed. Therefore, all button responses which exceed 20 seconds are classified as missed.

As described in the previous chapter. The researcher fills in the form in Appendix B5. each time a signal is received. With the timestamp at which the form is submitted, the duration between the signal and the submitted form can be calculated. This might be relevant as stopping to fill in the form could be an analogue of a user of Grippy finding the time to cope.

Figure 26: *Grippy being worn while cycling*

5.3 Results

In this chapter, the empirical findings of the auto-ethnography, experiment three, will be discussed. Personal anecdotes will be given as context and quantitative data will be used to evaluate the findings. To see the process with which these findings were obtained, see Appendix B4.

5.3.1 Vibration signal noticeability

Overall the noticeability of the Grippy signal was high, in all situations except for cycling. Besides cycling, some other factors did also influence the perceived noticeability of the vibration signal. These will also be discussed in this chapter.

Cycling greatly reduced noticeability

While cycling I missed 6 of the 13 signals. Which is about half. Some signals I only noticed when I used my other hand to check if the vibration signal was going off. This is especially interesting as I physically could not notice the signal even when I knew it was going off.

There are two factors which I assume to be related to not noticing the vibration signal. The vibration of the steer and the wind.

The vibration of the steering wheel masking the vibration of Grippy is very plausible. Different road conditions could even account for some signals being harder to notice than others. Unfortunately, I did not test cycling without holding the steering wheel.

Whether wind has a large influence on vibration noticeability is hard to say. I also experienced a drop in signal noticeability while the wind was blowing at a later date, which I discuss in the next subsection. However, when comparing the comments I made during cycling with the noticed signals there does not seem to be a correlation. I mentioned wind was blowing during three of the 6 missed signals and four of the seven noticed signals.

It was not possible for me to distinguish noticed signals from missed signals during the experiment. One time while cycling I commented that I believed I noticed the signal while the response time was above 20 seconds.

Noticeability reduced during changes in environmental factors

There were three times in which I found that the vibration signal became temporally less noticeable. There are likely many similar effects which, if they would happen at the same time as a vibration signal, would reduce the signal noticeability. This is relevant as I believe I could have missed those signals if they weren't continuous.

The first time, I was sitting on the couch and eating cereal. The living room was empty. When I was almost finished I moved the bowl to my mouth just as a vibration signal was sent. I recall feeling the sensation of the vibration, but not registering it as a vibration signal until I finished the movement. This could be caused by our bodies expecting some vibration when moving body parts and we filter them out.

The second time, the clock tower bells sounded at the same time a vibration signal was sent. I was outside with two other people and it was dark. I was distracted for a second and had to recheck whether the vibration signal was going off. During the situations where I was listening to music, sounds did not seem to influence vibration signal noticeability. It could be that the sudden change in sound caused the distraction and not the sound level itself.

The third time, when a signal arrived just before I felt a breeze of wind, well aware of the signal I noticed that the signal seemed to dip in strength while the breeze flew past. I was working in the garden on my own. The wind is known to cause vibratory noise and this might drown the vibration of Grippy. If wind-induced vibration noise reduces the noticeability of vibration signals this might also explain why cycling has such a strong effect on vibration signal noticeability.

The response times in these situations were 4,6 seconds, 7,4 seconds and 3,7 seconds respectively. This is above average as expected, but not the only reason for high response times.

Stressful experiences reduced signal noticeability

Stress could influence vibration signal noticeability. There were two situations in which I received a vibration signal not long after I was in a stressful situation. In both situations I reported the vibration signal feeling faint. I have had situations with similar environmental features in which I did not report the signals as faint. So it is unlikely that the environment alone could explain the situation.

The first occurrence, I just finished a computer game in which I repeatedly made mistakes which forced me to wait. I was sitting in my living room and people were talking all around me when the signal arrived.

The second occurrence I was stressing at the self-checkout in the supermarket. It took me some time to find my debit card and my mind had been racing. When the signal arrived I was walking towards the exit. It was reasonably busy in the supermarket.

My response time was quite fast in both situations: 1.9 and 2.0 seconds respectively. Which indicates that faint signals do not directly relate to slow response times.

5.3.2 My experience reacting to the vibration signal

Influence of signal strength on the signal response

I took my time responding to the signals of Grippy. While cycling I found that I took the time to check if my surroundings were safe, while talking I found I waited to finish a sentence and while uncertain I found I checked whether the signal was continuous before responding.

In total there are 6 occurrences where I mentioned taking my time to respond to signals. Three specific response times can directly be linked to this. 8,2 second, 4,4 seconds and 4,5 seconds respectively. But relaxed responses are likely the cause for other above-average response times as well.

In comparison, during two additional tests which were done at 100% vibration signal strength, I found the signal to be intense. In these situations, I felt compelled to quickly turn off the button. There could be multiple explanations for this effect. This could be because the signal was distracting to me, it could be because I did not want to alert other people around me or it could be because I was wanting to show off how quickly I noticed the signal.

It is unlikely that other people would pick up or notice the stronger signal while cycling. However, it is clearly audible in a silent room. I believe that the strength at which the user notices the vibration signal together with knowing that other people could potentially hear the signal creates an often incorrect idea that others will notice the signal.

Negative experiences with signals

Two times I mentioned negative feelings upon noticing a signal. It is important that both were very minor and quickly disappeared after the vibration was gone.

The first time, I was playing a racing game, by pressing the button I would have to quickly let go of the gas pedal which would influence how well I did. After the initial frustration, I accepted the situation and quickly pressed the button without losing too much time. I believe a part of the frustration came from the fact that I was not initially prepared to let go.

The second time, someone was talking directly to me when the signal arrived. I found the idea uncomfortable that Grippy distracted me from the person who was taking his time to explain something to me. I did report that the signal was appropriate at the time as the other person was unaware of Grippy’s signal and my reaction to the signal.

Apart from those two occurrences, I found that receiving the signals did not evoke strong positive or negative feelings.

Trustworthiness

When describing the qualities of partners, we explained that users need to trust that they will receive a signal when they need it. In the situation where the user is not confident that they will notice the Grippy signal, they will not be able to expose themselves as freely as is intended.

I noticed that I often forgot I was wearing Grippy. When testing, it became clear quite quickly that the vibration signals were easy to notice. I did not feel the need to check Grippy if signals were going off and instead trusted that I would know if an alarm was going off.

Initially, his was also the case initially while cycling. However, once I noticed I was missing signals I started constantly checking Grippy. There were also more occasions where I thought I may have felt something but didn’t. I found I did not trust the noticeability of the vibration signal during cycling.

While cycling I would check whether a signal was going off with my right hand. When cycling for the second time, checking with my right hand became a habit. I found that I liked this interaction as the very faint signal which triggered me to check was more un-intrusive than normal.

I found that after the cycling test, I still trusted Grippy in situations I tested before, however, in new situations I would be more alert until I successfully noticed the first signal.

Discreetness

Social situations were expected to influence the users' experience in reacting to Grippy's signal. During the experiment, I found no situations in which social situations limited me in pressing the button.

I found that responding with the button was a discreet way to interact with Grippy. Bringing your hands together is a quite common movement and it does not draw the attention of others. I found no situations in which other persons commented on me pressing the button. When asked the people who I was with if they noticed me pressing the button, they responded they did not.

I also found that I would more freely press the button when surrounded by strangers compared to friends. This could be influenced by how involved I was with the friends compared to the strangers. This might be because when you are with friends you draw their attention more, then you would draw the attention of a stranger who passes you in the mall.

Figure 27: Pressing the button while walking

Disruption from vibration signals

I found that responding to the vibration signal was not disrupting in most situations. Especially when I could not fill in the form. While watching a movie in the cinema for example I could follow the movie without problems.

I found that the 15-25 minute interval signals did not cause signal fatigue. However, when two separate 15-25 minute interval routines were started at the same time accidentally, I found that the short interval between signals became annoying.

In total around 20 signals were sent varying from 30 seconds in between to 20 minutes. Annoyance about the frequency came up when a signal quickly followed the previous signal. Around 3-5 minutes. However, I did not become even more annoyed every following time it happened. There did not seem to be an additive effect.

When two signals arrived within 30 seconds from each other, I noticed something was not right. That situation confused me more than it caused annoyance.

5.3.3 Experience filling in the form

We can relate finding time to fill in the form to users finding a way to cope with stress. Therefore it is interesting to look at how stepping away from the user's current activity to fill in the form was experienced.

As expected, because I had to stop what I was doing, having to fill in the form was very disruptive. This was especially strong in situations where other people were involved. The reason for this is that when there are other people the activity generally continues without you.

In social situations, I would often need to 'reconnect' to new conversations, or wait until the topic changed.

Social situations where I was needed for the activity to continue, where less disruptive but came with the added pressure of making other people wait. A good example of this was that while cycling together with others, we would constantly have to stop.

I was able to drop what I was doing to fill in the form most of the time. There were two exceptions to this.

First, when texting I found that I would finish the text message I was writing. I did not want to make people wait and were worried that I might lose my train of thought.

Second, when I was interacting with strangers I would wait with filling in the form until the interaction had passed. This happened two times when I was in the mall. The strangers were helping me and I did not want the strangers to have to wait until I finished filling in the form. Additionally, having to explain why I would suddenly fill in a form would have felt very awkward.

When looking at the form response time we find a strong influence on form response time from the familiarity of the people around.
I would put off filling in the response form when a stranger was helping me. In contrast, I found that I only hesitated to fill in the form when friends were talking directly to me, but would still end up filling in the form immediately. While walking in the mall I found that having to stop in a busy street bothered me.

5.3.4 Experience wearing Grippy

While testing the vibration signal interaction of Grippy, I wore the prototype for long periods of time. In this subchapter I will discuss my findings related to wearing and using the Grippy strap prototype.

I found that Grippy was comfortable to use for long periods. One evening during which I went to dinner, watched a movie and talked to roommates around a campfire I wore Grippy for 4:30 hours. However, I did take it off for bathroom breaks. I also found that I would forget I was wearing Grippy. Grippy was not actively on my mind and I often only noticed Grippy again when grabbing new items or having to wash my hands.

Physically, the bulk of Grippy limits the users in three ways. Most importantly, the glove does restrict the user when changing clothes. I found the glove got stuck in my sleeve while trying on clothes in the mall, and I found I waited longer before I took off my vest while cycling.

Secondly, I would rest my arm more often when wearing Grippy due to the weight. I would also move my hand less freely while typing and playing the piano. However, like all other times, this is something I got used to and stopped noticing.

Lastly, I found sweat builds up under Grippy, comparable to some watches. I did not find it to be excessive, however, if Grippy is intended to be used for longer periods, a more breathing design would help.

I found that the glove does not feel discreet. The blue box on the back of the Glove distinguishes it from regular gloves. I found that I would try to keep it off-screen when talking to others. This seemed also to be the biggest fear of other people who I talked to about Grippy.

However, I did not notice people treating me differently when wearing Grippy. When walking outside in the mall there were multiple occasions where the people could have given me strange looks or asked about the glove, but this did not happen.

I found that pressing the button was a discreet way to convey information to Grippy. It felt comfortable and I was confident that Grippy received the press. There were two moments in which I found I had problems finding the button on the back of Grippy. First, when I had just been stressed about my debit card, and second when I heard the clock tower bells at the time of the signal. In both of these situations I also experienced the vibration signal as less noticeable and being stressed or otherwise distracted could have had something to do with it.

Figure 28: Cleaning hands with Grippy on

5.3.5 The influence of environmental factors on noticeability

Other people, sound and whether the user was holding something all did not seem to influence the ease at which the vibration signal was noticed.

There is no drop on vibration signal noticeability, even when walking around in a busy shopping mall or talking directly to others. While gaming with loud music on, the vibration signal was still clearly noticeable. Which was also the case for signals that arrived while I was carrying around dishes and grocery bags.

Physical activity and vibration where both present in the cycling activity and could influence the vibration noticeability.

The cognitive load did seem to influence the vibration response time. In situations outside of the ‘studying’ activity, tagged as ‘high cognitive load’ the average response time was 1.3 seconds longer than on average. This difference was even larger in the ‘studying’ activity. While studying my response time was 1.9 seconds longer than average.

5.4 Discussion

5.4.1 Discussion regarding results

Overall the noticeability of the Grippy signal was high, in all situations except for cycling the vibration signal was noticed. However, there were moments at which the signal was briefly less noticeable, which might have been missed if the vibration signal was not continuous. Therefore, a signal which is noticeable during cycling and still continuous is ideal. The vibration of the steering wheel is the most likely explanation for this. While wind might also influence vibration noticeability the results on this are mixed.

We found that the vibration signal could cause frustration and uncomfort in specific situations. Not wanting to drop focus when being talked to, like happened in the uncomfortable scenario, is an example of not being respectful of the personal values of the user.

The vibration signal was discreet, and, in situations where the vibration signal was consistently noticeable, the vibration was also trusted. As expected we saw that the trust disappeared in situations where the user did not consistently notice Grippy which resulted in the researcher being more distracted by Grippy.

As expected, the disruption caused by the user having to pause what he or she is doing was significantly larger than the disruption caused by receiving and responding to the Grippy signal. During experiment three I found that the negative experiences correlated to this for me were having to leave a conversation I was part of, or making other people have to stop with what we were doing as well.

The Grippy glove does not feel discreet, but no negative experiences were encountered when wearing the glove. However, looking like a student who is trying out a prototype might have helped me in this regard and luckily other people are unlikely to harass people about these things in our society. Despite the interaction of pressing the button being visible to others, it was often unnoticed as the action is quite natural. I could imagine, however, a user finding it uncomfortable that others can see the action.

One factor that was not taken into account in the setup of the test was the wind. Vibrations or sensations caused by the wind might hide vibration signals. Additionally, we found that changes in the environment might also hide vibration signals, where initially we expected all distractors to be constant. Other people, sound and whether the user was holding something did not seem to influence vibration signal noticeability.

5.4.2 Reflection on the chosen activities

In the previous subchapters all the empirical insights gained from the autoethnographic experiment are explained. This subchapter aims to more structurally discuss the hypotheses made when choosing the various activities.

Cycling
The vibration signal was indeed not noticeable during cycling. However, this only occurred half of the time. Additionally, at times I could not feel the vibration signal even when I knew it was going off.

Therefore we can assume that at least part of what makes vibration signals not noticeable during cycling is physical, and changes over time. This would point at wind and or road conditions rather than physical exercise.

Studying

We expected that the vibration signal might not be noticed while formulating a sentence or doing other heavy short-term mental tasks. And we actually saw some support for this in the longer response time related to these kinds of signals. However, it is hard to say if in those situations the response time was longer because the signal was not initially noticed, or that the signal worked as intended and I had time to finish my train of thought before responding.

Groceries

The most stressful moments during Grocery shopping were expected to be checking out and having to hurry to find what type of food you are looking for. I had no problem noticing the signals when grocery shopping, though these situations of high stress might influence noticeability as we did see support for that when I received a signal just after I lost my debit card.

Piano playing

We expected that the activity of playing the piano might hide the vibration signal. I did not notice this. The vibration signal is quite different from hitting the notes. Though, a faster player might have a different experience. Sound level did not seem to influence noticeability in any of my experiments.

PC Gaming

Games which require activity from two hands, fast reactions and quick thinking are a great distraction. However, I was also really focussed on being aware of new ‘threats’. The vibration signal was very noticeable when I was playing. I did experience very short frustration when I was playing a game which occupied both my hands, as I had to play ‘less optimally’ to respond to Grippy.

Public transport

Public vehicles were expected to vibrate a lot which could hide the vibration signals. However, the public transport surrounding Delft is quite still and I had no problems noticing the vibration signals. I did not mind the other people present as they did not seem to pay attention to me.

Conversation

We expected that responding to vibration signals while talking, might be noticeable to the person you are talking to. However, that did not seem to be the case as the persons I was talking to did not remember me pressing the button afterwards. Responding to a signal when someone was talking directly to me was uncomfortable, and receiving signals during conversation is likely a relevant situation to continue exploring.

5.4.3 Review of the continuous vibration signal

In the third experiment a continuous signal, at the low vibration strength was used. This continuous vibration signal can be used to convey complex information to the user while also ensuring that the vibration signal is properly noticed. This is relevant when signals with different meanings need to be sent to the user. For example, the difference between a 'battery low' signal and a 'stress alarm'.

This vibration signal was found to be discreet in all situations, non disrupting in most situations (as described in the previous chapter), and not noticeable while cycling. The continuous vibration signal succeeds in creating rest and it allows the user to respond to signals after he finished his immediate train of thought.

However, because the continuous signal does not stop on its own, The user has to press a button to end the signal. This is more work than doing nothing and when the user is not able to press the button the signal might induce more stress in the user. Reacting to the vibration signal caused disruption in two types of situations.

First, when dropping focus requires the user to make a sacrifice this could cause frustration in the user. For example, when walking around responding to the Grippy signal is no problem, but when both hands were occupied while playing a racing game the signal caused some frustrations. Second, when reacting to the vibration signal caused me to lose focus when listening to someone talking directly to him, this clashed with my values and made me uncomfortable.

I believe the two situations described above might be acceptable when the user has to become conscious of the onset of stress. However, these situations illustrate how these signals can be disruptive to the user and false positives should therefore be avoided as much as possible.

I experienced a continuous signal at low vibration strength as a comfortable way to be reminded to do something, it was resistant to temporary reductions of noticeability and allowed me to finish my train of thought.

Section 6: Insights

6.1 Reflection on the knowledge gaps

6.1.1 The relation between vibration strength, noticeability, audibility and disruption.

Noticeability, audibility and disruption are related to the ‘qualities of partners’, that are discussed in chapter 2.3. Noticeability is required to build trust. Disruption can lead to situations that are not respectful and the audibility of a vibration signal causes it not to be discreet. How these three qualities relate to the strength of the vibration signals was one of the knowledge gaps this thesis focussed on.

At the highest vibration strength, the continuous vibration signal was noticeable, audible and disrupting. At low vibration strength, the vibration signal was not audible and not disrupting in the quietest situations. However, it was also not noticeable while cycling.

Figure 29 shows the visualization of how vibration strength could influence noticeability, disruption and audibility. Here the existence of the hypothetical area A would indicate that audibility alone is not sufficient as an upper threshold on vibration strength and the existence of area C would indicate that situations exist at which vibration signals can not be discreet and noticeable at the same time.

We found that area A can likely exist in non-quiet environments. When gaming with loud music we found that sound likely did not influence vibration noticeability and the vibration signals were clear.

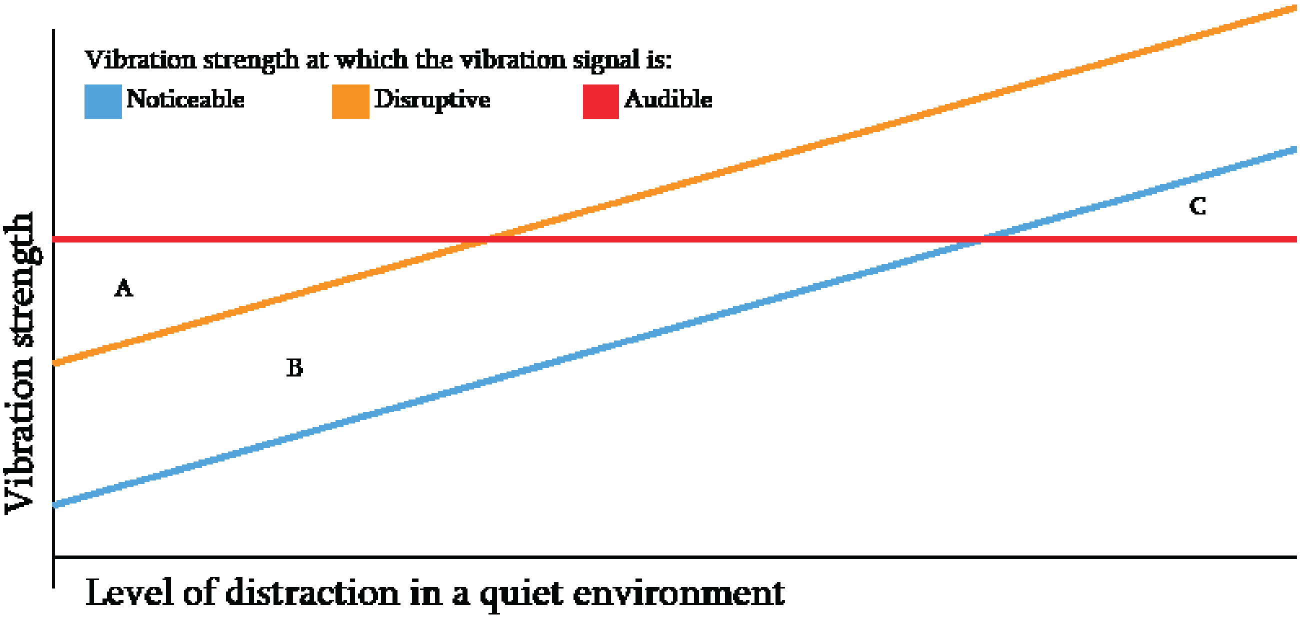

Figure 29: Visualisation of possible vibration strength impact on noticeability, disruption and audibility.
With: A: Area where audibility alone is not an appropriate lower threshold on vibration strength.
B: Area in which the vibration strength is appropriate.
C: Area where vibration signals are not a discreet way of alerting the user.

Therefore it is logical to assume that in loud but non-distracting environments, such as speaking in public, the signal could be disrupting to the user before it is audible to others.

Area C likely doesn’t exist. The vibration strength can likely be increased in situations where the vibration signal is masked in other situations. While cycling we noticed that the vibration signal was likely masked by the wind or vibration of the steering wheel. We expect that the wind and or vibrations in the steering wheel would cause some sound, which would be able to mask the sound generated by the vibration motor.

It is possible that the level of disruption caused by the vibration signal increases with noticeability and creating a completely non-disrupting signal is impossible. This is also supported by Zheng & Morrel (2012) who found that the noticeability of haptic signals negatively correlated with the pleasantness of those signals. We should therefore aim to create just-noticeable vibration signals that are acceptably easy to ignore.

As the vibration signal was not noticeable during experiment three. An adaptable vibration signal is likely needed to keep the vibration signal just-noticeable in other situations.

In conclusion, audibility, disruption and noticeability all increase with vibration strenght. However, vibration signals are quite noticeable and it is likely that for each situation, a vibration strength exists that is appropriate for that situation.

6.1.2 Environmental factors that influence vibration signal noticeability

We explored the influence of five environmental factors which could influence vibration noticeability. These are: the vibration of the wrist, environmental noise, physical activity, cognitive load and the presence of other people. Because the vibration signal was noticeable in almost all situations, drawing correlations of conclusion on noticeability is hard.

In my experience environmental noise and the presence of other people have no influence on vibration signal noticeability and physical activity is unlikely to have a large influence of vibration noticeability. In experiment three there were no missed signals in situations where there was loud environmental noise or there were multiple other people present. Roumen, Perrault, and Zhao (2015) found that physical activity did not influence noticeability of vibration strength on signal noticeability in the context of a ring-type device.

The vibration of the wrist and cognitive load did seem to influence vibration signal noticeability. Vibration of the wrist is a factor which was unique to cycling and cognitive load because it came up multiple times during the autoethnographic descriptions of less noticeable vibration signals. While it is true that physical activity might also create some vibration in the wrist, these are likely smaller than the vibration in the wrist caused by cycling.

Blowing wind is an environmental phenomenon which seems to reduce the noticeability of the vibration signal. If the influence of wind on vibration noticeability is significantly large this could pose an additional challenge for creating an adaptive vibration signal strength. As the wind speed then has to be taken into account in all outside situations. However, we can not make solid conclusions about the effect of wind speed. During cycling, the presence of strong wind did not seem to influence noticeability, and while sitting in the garden, the reduced noticeability during the gust of wind could be caused by the sudden change in the environment.

There is some indication that not only the environmental factors themselves but also changes in the environmental factors cause missed vibration signals. One hypothetical explanation for this could be that we get used to the sensations of our surroundings and that small changes such as vibration signals will thus stand out in most stable environments. However, when we experience a change in environment we might ignore new sensations more easily as a change in sensation is expected. If so, it would be natural that these changes in the environment could be caused both externally, such as in the case of a gust of wind, and by ourselves, such as in the case of turning our wrist.

In conclusion, more targeted research is needed to fully understand which environmental factors influence vibration signal noticeability. Physical activity, sound and the presence of other people seem to have no influence on vibration signal noticeability. Changes in the environment, the vibration of the wrist and cognitive load do seem to reduce the noticeability of vibration signals and lastly, wind could have a strong influence on vibration signal noticeability, but this is quite uncertain.

6.1.3 How to design respectful stress alert signals

When introducing respectfulness in chapter 2.3 we proposed two goals. First, the alerts should accurately convey the severity of the alert to the user. This allows the user to make informed decisions and does not make the user overcompensate ‘to be safe’. Second, the user should not be inhibited in his actions until he means to receive information from Grippy. In this way, the user will be able to continue what he was doing and does not lose autonomy.

A stress alert, also called an intervention, could be by nature disruptive to the user. To convey the severity of the alert, the user needs to be able to recognise some quality of that vibration signal. For example, the pattern, waveform, duration or intensity. Sonneveld & Schifferstein (2008) found that it is hard for users to recognise different qualities of vibration signals, which is also supported by the results of the first experiment. Therefore, pattern sequences are likely the best way to accurately send different signals. However, the first experiment showed that participants could not recall the signal pattern they received when formulating a sentence or recalling information and thus had to drop focus and later start over. This is something we have to avoid.

I used a continuous signal at low vibration strength as means of respectfully alerting myself during the third experiment. The idea behind this was that the low strength vibration signal would be easily ignored or possibly not even noticeable while in the middle of a sentence and would thus allow the user to finish his or her train of thought. Then, a few seconds later, when the user finds a moment of silence, he will react to the vibration signal that is going on.

There were two possible problems with this approach. First, the continuous signal might be too disrupting for me to continue what I am doing. And second, that I might continue to ignore the signal or not notice it at all. However, I did not find this to be the case. I found that I could finish my train of thought and respond to the signal in a relaxed manner. This delay was often quite small. The response times were 3,8 seconds on average.

There is quite a broad range of vibration signal strength that feels comfortable to the user. However, as discussed in chapter 6.1.1 the levels of noticeability, audibility and disruption depend heavily on vibration strength. Using a continuous signal makes it so that in situations where the vibration signal is disrupting, it will be disrupting continuously. This places a higher focus on creating just-noticeable vibration signals.

In conclusion, a continuous signal could be a respectful way of sending stress alerts to the user. It is both respectful and triggers a response within a reasonable time. However, when using a continuous signal the need for just-noticeable vibration signals increases.
A strong vibration signal that is continous is more disrupting than a strong vibration signal that quickly stops.

6.2 Insights on the Grippy glove

6.2.1 Two ways of wearing the strap based prototype

There are two Grippy prototypes. One glove based prototype and one strap based prototype. I noticed that there are two ways to put on the glove based prototype.

Strap over hand

You can wrap the smaller end of the strap around your palm and back of the hand. Connecting the end back to the velcro part that reveals itself. Afterwards, you wrap the rest of the strap around the wrist until the electronics box rests on top of your wrist and the other end of the strap connects to yet another velcro patch.

This leaves the pressure pad only connected on the top of the hand. The pad will ‘crawl up’ and move up from the hand when raising your palm. And prevent you from lowering your palm. Additionally, the velcro will often get loose from the pulling.

Additionally, the pressure strap is hard to reach in this position as it is positioned quite far up the arm. When balling your fist as you normally would, your fingers will ‘overshoot’ the pressure pad.

Tucking the strap

By letting the end of the strap fall under the larger strap you wrap around your wrist, you position the pressure pad diagonally on your wrist. This allows for a stronger fit.

It also allows more movement of the hand in the downward connection. Because the strap can move relative to your hand palm.

Lastly, the pressure pad is lower on the wrist. On this location, some of your fingers will hit the pressure pad regardless of how you clench your fist.

The tradeoff for this is more limited thumb movement and the additional difficulty in putting Grippy on this way.

For the third experiment, I followed the second routine as well. But as an additional step, I put my thumb under the pressure pad and folded it back over itself. This way it did not limit my hand movement and the extra bulk on Grippy did not get in the way.

Figure 30: Putting on Grippy with the strap over the hand

Figure 31: Pressure pad 'crawling up' the palm.

Figure 32: Putting on Grippy by tucking the end of the strap

Figure 33: Diagonal position of the pressure pad

Figure 34: Folding pressure pad over the thumb

Figure 35: Wrist Grippy

6.2.2 Insights on using Grippy without the pressure strap

The pressure pad is currently what sets the physical prototype apart from a regular smartwatch. However, when using Grippy in daily life we encounter a few problems.

The pressure pad falsely gives inputs when the user is grabbing objects. When pinching or gripping small objects the pressure pad folds which creates resistance as can be seen in Figure 36, and the pressure pad gets in the way when washing your hands.

When wearing Grippy on the wrist, these drawbacks disappear. However, the user can no longer self-report with a single hand. Instead, you use your right hand to press the button on the back of Grippy.

One fear I had with Wrist Grippy is that the strap would move around on my arm. But this turned out not to be the case. The rigid electronics body on the back of Grippy prevents the strap from rotation around my arm. The electronics housing can be seen in Figure 37.

*Figure 36:	Puttin on Wrist Grippy tightly*

*Figure 37:	Pushing the pressure strap over the thumb*

6.3 Realisation of the learning objectives

At the start of the graduation project, four learning objectives were defined. In this chapter, I will briefly discuss the goals of each learning objective and what I felt I have learned.

In general, the project took a different direction than I had originally planned. This was not unexpected, as it became clear quickly that this project would have a quite open and explorative nature. The learning objectives I had did not directly relate to the core of the graduation project. Instead, they were additional lessons I wanted to learn along the way, which I feel had to do mostly on my own.

Design some form of an intelligent system

Goal

The original proposal of the graduation project would have Grippy construct a digital model of the user with the data it collects during use. This model could then be used to personalise Grippy. I was interested in either building this model or explore what it could be used for.

I believe the vague wording of this learning objective indicates my initial level of knowledge on both the subject of intelligent systems and the Grippy project. I had a decent background both with working with rapid prototyping tools and writing code. Using my graduation project to learn more about creating intelligent systems felt like a natural next step.

Realisation

At the start of this project, it was not clear what ‘personalising’ Grippy meant. The scope of the project was narrowed down to adapting Grippy’s vibration signal. However, both Catholijn Jonker, who advised during the early stages of the project, and Alessandro Bozon had concerns that Grippy would not collect enough data to be able to reliably generate results.

During the project, the scope shifted to testing whether it was possible to have a vibration signal that is both noticeable and discreet I believe that in the context of this graduation project, intelligent systems ultimately did not have a place as there was already a lot of work to be done on both the experimental design and the programming of the prototype.

Work and continue on existing software

Goal

I had done self-taught programming next to my study. I created a smart home system on a raspberry, and have written multiple personal utility applications for android. However, because I never had to work with any code other than my own, I liked to continue on an existing project and add to already existing code. Both to learn new things, and to check how I compared.

Realisation

This went well and I was able to continue with the software without any hiccups. The software implementation that was needed was basic. Because of this, there was no back and forth on software implementations needed with the supervisory team and the programming overall felt separate to the main graduation project which mostly focussed on the experimental design.

Because there were no strong requirements on the code changes, and no discussion was required.

I believe I was not challenged as much as I could have been. I still achieved my goal of experiencing how it is to continue with someone elses project and how to apply that to my further work.

Work hands-on with a prototype

Goal

For many of the same reasons as with working on existing software, I wanted hands-on experience with a prototype.

Realisation

The Grippy prototype allowed me to do work hands-on with a prototype very well. I was able to make quick software changes and I was forced to come up with solutions that dealt with the limitations of the prototype. However, the prototype itself was difficult to change. It was not designed for easy adaptation, which became an issue when I wanted to switch out a vibration motor to a stronger one.

Do fast iterations

Goal

While many courses in 'Integrated Product Design' offer the full design process in a single course, few courses involve iterations in the learning process. For this project, I wanted to use a research through design process.

Realisation

This came to fruition when writing the code for Grippy. However, a large part of this project has also been experimental design. Because I needed approval from the ethics committee before I could do experiments, I was not able to implement multiple iterations in the early experimental design aside from the pilot tests. Wich I will discuss more in Chapter 6.4.

6.4 Reflection on the experimental design

This graduation project and the accompanying experiments have all been conducted during the COVID-19 pandemic. This, of course, influenced my experiment design.

Participant studies

The goal of the first experiment was to find at which point vibration signals stop being noticeable. Social situations were relevant for this, and as such, I needed a way to emulate social situations.

Video calls are an acceptable way of talking with other people but are limited in two ways. Because of the small time-delay in large groups, people will often start talking at the same time. And when multiple people talk at the same time it is hard to understand what is said. Therefore I opted to go for a formal social situation.

The participant would join a video call and be introduced to the 'judges'. Each of the judges had a role and therefore besides the participant, only either one of the judges or the researcher was speaking.

I had to make concessions when choosing participants. As I was using video calls to create social interaction, using participants outside of the house was a possibility. I had the luxury of living with 15 roommates house which gave me access to multiple participants which I could be in physical proximity with. However that would mean that my sample would likely be biased. However, if I tried to avoid this bias the prototype would have to be transported in between participants in between each test. By choosing to use my roommates I saved time which allowed me to test on more participants and reduced physical contact with others.

Introspective study

For the thirds experiment, I decided for an introspective study in which I was both the subject and the researcher. This had multiple benefits which were not related to the pandemic, such as me having experience with the prototype and being able to experience the interaction myself. However, due to fact that no participants are neccecary introspective studies are less affected by the measures taken against the COVID-19 than participant studies are.

From a broader perspective, it would make sense to do the autoethnographic studies during Covid-19 and do possible future participant research after the pandemic.

In the case of the introspective study, the restrictions in the Netherlands were quite lenient and much of daily life could continue as normal. However, the argument can be made that an ethnographic study during a lockdown might not be representative of normal behaviour.

Things I would do differently

If I would do the project again I believe I would stick with the experiments I did, as they provided interesting results and were achievable during the pandemic.

However, I would start experimenting with the Grippy prototype earlier. Receiving ethics approval for the first experiment took multiple weeks.

My initial expectation was that the outcome of the first experiment would show me a clear direction for the project. However, I believe that I could have gotten an indication earlier if I had done small scale tests on myself.

I would also have done more experiments like the second experiment discussed in the report. The second experiment only took three days of work for the design, execution and evaluation of the results. Which is quite efficient. Still, there were a lot of improvements to the second experiment I could make if I could do it again. For example, I would include a tuned decibel meter and generate various background sounds to test how audible scales with increasing environmental noise levels. However, looking back on the project I believe that it might be faster to do the second experiment twice rather than doing it perfect the first time.

Lastly, I would start earlier with building a support team around me. Working at home during the pandemic was hard for me, and I clearly noticed the lack of a working environment. I started calling my cousin daily to discuss life and our individual project, which really helped.

Section 7: Recommendations

7.1 Essential attributes of stress alert vibration signals

In order for a vibration signal to be trustworthy, discreet and respectful, it needs to be adaptive, continuous and just-noticeable.

7.1.1 Designing just noticeable vibration signals

The experiments have shown that just-noticeable vibration signals might prove relevant in designing discreet and respectful interventions when helping people during the onset of stress. The just-noticeable vibration signals can not be heard or otherwise noticed by other people around the user. Receiving just-noticeable signals also did not interrupt my train of thought, while stronger vibrations did interrupt me.

There are two types of situations to take into account when going from 'mostly' noticeable to 'always' noticeable.

Situations in which weak vibration signals are not noticeable

All missed signals happened during cycling. Importantly, at times the signal was unnoticeable even when I knew it was going off. This indicates that the process of hiding the signal must be physical. The wind, the vibration introduced by the steer and physical activity could all be factors here.

A stronger vibration signal made all vibration signals noticeable. However, this stronger vibration signal might be noticed in the quietest situations and therefore an adaptable vibration signal is needed.

Situations in which noticeability is temporarily reduced.

Some short term distractions can briefly hide the vibration sensation. These are physical movements of the wrist, wind, and unexpected sounds. While it is uncommon that these moments overlap precisely with the vibration signal of Grippy, it is possible and happened multiple times when testing.

These short moments of reduced vibration noticeability are often situation independent and the timing of the signal is hard to predict. Therefore, an adaptive signal will likely not be a good solution. During the third experiment, these moments were not missed because a continuous vibration signal was used. A continuous or repeated signal is likely the best solution to deal with temporarily reduced noticeability due to environmental factors.

Conclusion

Vibration signals for use in interventions need to be adaptive, continuous and just-noticeable. In some situations, like in cycling, the soft signal is physically not noticeable and a stronger signal is needed. A stronger signal causes more disruption, and might in some situations no longer be discreet. Lastly, the vibration strength needs to be adaptable to situations like cycling, either manually or automatically.

7.1.2 My thoughts on making an adaptable signal

When designing vibration signals on the threshold of noticeability, we need to understand situations and factors which cause the signal to be missed.

Some situations, like cycling, will physically drown out just-noticeable vibration signals, making it impossible for the user to notice. In these situations, the vibration strength will need to be made stronger. In the case of cycling, manual adaptation would be possible, however, this is not risk-free as the user might forget to do this. In this case, adapting the vibration signal based on moment speed might be the solution.

Movement speed while cycling could range from 10 km/h to 45 km/h. This could be detected by GPS, in the same way that apps like ‘Pokemon Go’ use movement speed to block users from cheating by cycling around. Increasing the vibration strength when within this movement speed range would accurately distinguish

cycling from most inside activities, but will also distinguish it from taking public transport. During other activities, like running or skating, the higher vibration strength will likely be appropriately discreet as well, though it might feel a bit strong.

One case which might lead to problems and does fall into this range is driving 30 km/h through a neighbourhood in an electric vehicle. So this has to be taken in mind.

7.2 The Grippy Prototype

There are two aspects of the wearable which can be improved: The comforting signal and the fact that the hand is covered up.

Creating a comforting signal with the vibration motor does not come across. The vibration signal did not evoke strong positive or negative feelings for me in the auto-ethnographic study. This is fine as a formal message to the user and is likely preferable when conveying simple information. However, it is recommended to look into other actuators to evoke feelings of support. Using pressure to create a feeling of 'holding' might be interesting. Though, it might also feel artificial and restrictive.

Grippy has been made a glove to support the clench action as a way of communication. The clench action as a way to interact with Grippy feels quite nice when the pressure pad is positioned nicely. However, I believe that the benefit of the clench action does not properly weigh up against the downside of Grippy being a glove.

The glove design needs to be taken off when the user is using the bathroom and is visible to other people. I suggest switching to a wrist-based design as the same functionality can be achieved. With the notable exception of being able to operate Grippy using one hand.

A sufficiently advanced programmable smart-watch with an easy to reach button could be a substitute for Grippy in its current form. The one-handed design was initially proposed as a discreet way to interact with Grippy. But using a second hand to operate Grippy was unnoticed by other people I interacted with.

7.3 Future research

In this thesis, I have explored the complexity of just-noticeable vibration signals and how much there is still to learn. I have used the Grippy prototype as a means for this, and as such, the prototype has also been properly tested. I believe future research should focus on testing the assumptions and predictions made in this thesis report and aim to better understand to what extent the insights of this study are relevant to people suffering from daily stress.

7.3.1 Just-noticeable vibration signals

In this experiment, we explore the attributes of just-noticeable vibration signals. These attributes are based upon two findings.

First, I found that just-noticeable vibration signals were easy to ignore for short amounts of time. However, this is not generalizable. Whether other people experience this the same way has to be researched. If softer perceived signals indeed trigger a more relaxed response from the user, that is an additional argument that just-noticeable vibration signals are preferred over strong vibration signals even when discreetness is not a concern.

Second, cycling was the only situation in which the lower strength vibration signal was not noticeable and the recommended way to dynamically adapt the vibration strength is made on the basis that there are no other situations where this is also the case. Whether this drop in noticeability was caused by the wind, the steering wheel vibrations or the physical activity needs to be researched further. Grippy also needs to be tested in more situations in which these factors could also be present. For example, flying. When flying multiple people are seated close to each other, there are background noises and vibrations from the engines, and people are limited in movement.

7.3.2 Stress introduced by a continuous signal

One of the concerns surrounding implementing a continuous signal was twofold. First, having to tell the glove to stop the signal is an additional thing the user has to do, therefore possibly causing more stress. Second, in situations in which the user is not able to turn off the continuous signal the signal could cause additional stress to the user.

Another concern has to do with learned behavior, if any vibration constantly predates panic attacks, a user might unconsciously draw connections between the signal and the panic attack. I do not believe this to be a primary concern, however, it might be a relevant area to explore.

Both of these theories need to be tested in the context of a continuous signal.

7.3.3 Small experiments

Outstanding questions which I believe should be testable relatively quickly include, testing the attributes of the vibration motor at 40% of maximum vibration strength, testing whether vibration from the hand by for example a vibrator or toothbrush can mask the vibration signal, and testing the influence of wind on vibration signal noticeability by using a hairdryer or fan.

7.3.4 Additional literature research

Due to the limited scope of this project, only a limited amount of time was spent on literature research. Most of this was to get a grasp on daily stressors and how receiving vibration signals might influence them.

While it is unlikely that many of the steps in this project, such as looking at ‘just-noticeable’ vibration signals, have not been done before, no papers detailing previous attempts were found. Excluding the keywords ‘models’ ‘whole-body’ from the search already helped filter out some of the research detailing the harmful vibrations of heavy tooling. Though the citations used in the papers cited would likely be a good start for new research.

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Appendices

Appendix A1: Design of the experimental tasks

Listening

Initially, a 500-word story was chosen to be read to the participants. This ran into two problems. First, the story was difficult to follow which caused some pilot participants to lose attention. Second, reading the story took significantly longer than necessary and unnecessarily increased the experiment duration.

First, the story was cut down to around 200 words, which took around 3 minutes to tell. Then, the actor telling the story would rewrite the story in his own words and tell the story to the user from memory.

By telling the story from memory, the flow of the storytelling became more natural and it was easier for the participants to follow. This did mean that the content of the story changed a bit per participant, but this was seen as not a big concern as the content of the story was not relevant to the research.

Small-talk

Small-talk was a difficult task to design, because, by nature, it is hard to control. One problem we ran across was that the small-talk became more of an interview. With the actor and the researcher asking questions and the participants quickly answering.

The ability to make conversation with the participants varied from person to person. In the final experiment, a peer of the participants was used for the small-talk. The communal knowledge she shared with the participants helped in the conversations.

This did mean that one of the two ‘judges’ in the experiment was known by some of the participants.

Presentation

The participants were asked to retell the story of the listening task as accurately as possible. However, when the participants were not sure about facts, they would skip over them and not fill the full two minutes.

Afterwards, the participants were instructed to talk for at least two minutes. The initial expectation was that this would put too much focus on the experimental setting of the test. However, it worked.

The focus of the participants switched from telling what they knew for sure, to improvising on the spot to fill the two minutes.

While few of the retellings of the listening exercise were accurate, the participants were fully occupied with presenting for the required two minutes it took for the signal sequence to finish.

Puzzle-solving

The first puzzle that was selected, puzzle A, was too difficult for the pilot participant. The participant quickly stopped trying to solve the puzzle. Additionally, the participant had to spend quite a lot of time understanding the puzzle first.

Afterwards, I tried to solve multiple logic puzzles and choose a puzzle which consisted of multiple steps but could also be explained in a few sentences. Two minutes is quite a short amount of time and even relatively simple puzzles fit the requirements. This puzzle performed perfectly for the first eight participants. However, in between participant eight and nine, the puzzle was leaked and needed to be replaced.

Puzzle C is a puzzle that is seemingly easy but requires writing it out and has multiple steps to solve. The big downside of the puzzle was the additional text required to explain the puzzle. However, it fulfilled the requirements.

Appendix A2: Listening task story

Mansa Musa was emperor of Mali who was considered the most wealthy person to ever live. He became the ruler of the Mali Empire in 1312. Under the rule of him, the empire grew fast to occupy a sizeable portion of West Africa. And Musa himself gained a big amount of wealth by trading stuff from the Atlantic coast to the inland, and parts of the Sahara Desert. By the time of 1324, Musa's wealth had been well-known by the world outside of Mali.

Mansa Musa was a devout Muslim. And there was a time when Musa decided to set off on a pilgrimage (a voyage) to Mecca, a city that was 4,000 miles far away. But he did not travel by himself. He travelled with a caravan composed of camels and horses carrying nearly limitless goods, including Persian silk, golden staffs and salt.

Of course, this group and the spectacular wealth were noticed by residents of the territories that Musa passed through—including Egypt. When Musa arrived in Egypt, he was invited to meet with the sultan. But he refused this meeting at first because according to the Egyptian tradition, he had to kiss the ground and the feet of the sultan. In the end, he was forced by the soldiers of the sultan to attend the meeting and greeted the sultan according to the tradition.

After this, Musa left Egypt. But instead, he showed his generosity to the residents of Egypt by leaving behind him a big amount of gold which was a rare resource and greatly appreciated by the people of Egypt. However, it turned out Musa's gifts of gold actually depreciated the value of the metal in Egypt, and the economy took a major hit. It took 12 years for the community to recover.

This text is adapted from a story found on history.com .(2018)Appendix A3: Puzzle-solving task puzzles

Appendix A3: Puzzle-solving task puzzles

Logic puzzle A: The king’s dilemma

The King of a small country invites 1000 senators to his annual party. As a tradition, each senator brings the King a bottle of wine. Soon after, the Queen discovers that one of the senators is trying to assassinate the King by giving him a bottle of poisoned wine. Unfortunately, they do not know which senator, nor which bottle of wine is poisoned, and the poison is completely indiscernible. However, the King has 10 prisoners he plans to execute. He decides to use them as taste testers to determine which bottle of wine contains the poison. The poison, when taken, does not affect the prisoner until exactly 24 hours later when the infected prisoner suddenly dies. The King needs to determine which bottle of wine is poisoned by tomorrow so that the festivities can continue as planned. Hence he only has time for one round of testing. How can the King administer the wine to the prisoners to ensure that 24 hours from now he is guaranteed to have found the poisoned wine bottle?

Logic puzzle B: Four litres.

You have a three-litre and a five-litre measuring bucket. You wish to measure out four litres. How could you do that?

https://www.folj.com/puzzles/easy.htm

Logic puzzle C: The Cubes

A corporate businessman has two cubes on his office desk. Every day he arranges both cubes so that the front faces show the current day of the month.

What numbers are on the faces of the cubes to allow this?

Note: You can’t represent the day “7” with a single cube with a side that says 7 on it. You have to use both cubes all the time. So the 7th day would be “07”.

https://www.folj.com/puzzles/easy.htm

Appendix A4. Information accompanying informed consent.

Interacting with haptic signals in social conversation.

Grippy is een slimme handschoen waarmee gebruikers kunnen communiceren via een druksensor en een vibratie motor. Het doel van dit onderzoek is om inzicht te krijgen in hoe gebruikers de interactie met Grippy ervaren in sociale situaties. Tijdens dit onderzoek zal je onder andere videobellen met vreemden. Hierin zal je te zien en te horen zijn.

Tijdens dit onderzoek verzamelen wij en verscheidenheid aan informatie bestaande uit:

- Uw hartslag
- De druksensor data gemeten door de handschoen.
- Uw opmerkingen en handelingen voor, tijdens en na de test.

De data die wordt verzameld wordt vertrouwelijk behandeld. Uw naam zal via een sleutel gekoppeld worden aan een deelnemersnummer. Hiermee kan uw data in een vervolgstudie worden geïdentificeerd. Na afloop van het onderzoeksproject zal deze sleutel worden vernietigd. Uw data zal geanonimiseerd in een beveiligde elektronische omgeving van de TU Delft worden opgeslagen voor een periode van maximaal tien jaar. De antwoorden op de vragen zullen met behulp van statistische technieken in hun samenhang geanalyseerd worden. Deze resultaten zullen worden gebruikt voor wetenschappelijk onderzoek en voor educatieve doeleinden.

Ook zult u tijdens dit onderzoek komen in contact komen met andere personen. Er zal van het worden gevraagd vertrouwelijk met de informatie die ze ontvangen om te gaan. Maar alles wat u tegen hen zegt is op eigen risico.

Appendix B1: Choosing continuous vibration signal

By doing a second test and iterating on the Grippy prototype, we can test changes made to the proposed functionality of Grippy. The main change to be implemented should allow the user to more easily notice and remember the meaning of the vibration signal.

Problem

It is relevant for Grippy to be able to send varied information to the user. For example, the difference between ‘Do you want to go for a challenge?’ and ‘Are you ok? You are getting very stressed’.

During the first experiment we noticed that even at the highest vibration strength, the response accuracy of the users capped just above 80%. Also, participants reported not immediately being able to focus on the signal when they were in the middle of a sentence or were holding up information mentally.

The participants of the first experiment had difficulty remembering the quality of vibration signals even after short intervals like ‘finishing a sentence’. The participants also reported being unsure whether they felt a signal and did not know how many vibration signals occurred during a test.

To have less impact on the user’s daily life Grippy should allow users to finish these short term mental tasks. Especially in social situations where having to stop in the middle of a sentence might draw unwanted focus on the user.

However, having the user hold the signal in memory while doing this could cause interpretation errors or additional stress.

Therefore, it would be nice to find a way to present the information Grippy sends to the user at a point when the user can pay attention to it.

Also, for the experiment, a continuous or repeating signal has the benefit that it will eventually be picked up. If there is a situation where the signal is not immediately picked up, the described situation from the moment where the user does pick up the situation can tell us a lot of what aspects might be the reason that the signal was not picked up. By comparison, a single signal will give no insights when missed.

Persistent signal options

Repeat the last signal

We could also allow the user to listen back to the signal, much like you would listen back to a voicemail. This would mean the user does not need to respond immediately and can correctly retrieve the meaning of the signal. However, this again results in the user having to keep remembering the signal in mind when finishing his train of thought. Additionally, if the user misinterprets the signal initially he might not check whether the actual signal matches his recollection.

Continuous signal

By sending a continuous signal the signal will still be there when the user has finished his thought. The user can then turn off the signal at the moment he would process the information. One of the concerns with this approach is that the continuous signals might be disruptive or cause additional stress to the user.

Snooze

If we allow the user to snooze the continuous signal we have to determine the next right time to send the signal. Because it is unknown how long the user needs to finish his immediate train of thought he might have to hold off on starting a new thought until the signal comes back, or might not be finished at the moment the signal returns again.

Stop and Go

The user could be allowed to stop and restart the signal. This would still require the user to immediately respond to the user. However, if the pausing would go instinctively it would not cause additional stress to the user. Though, when the user gets in the habit of stopping

Continuous signal

While testing with the continuous signal I did not encounter a need for a snooze implementation. I would finish my train of thought and calmly press the 40% strength signal. However, this might be related to signal strength. When doing a test with continuous signals at 100% vibration intensity I would be distracted and quickly press the button. Which indicates that vibration strength might have a larger impact on the experience of continuous signals than reported in the first experiment, which dealt with short-duration signals.

Appendix B2: Strengths and weaknesses of researcher introspection

In their 2019 paper, Haian Xue and Pieter M.A. Desmet propose “a resurrection of introspection as a valid approach to investigating subjective experiences.” They discuss the relevance of researcher introspection in human-centred Design and propose ways in which planned researcher introspection could add to design research.

Benefits

(Xue and Desmet, 2019) propose four benefits of Researcher Introspection which are relevant to this project.

Researcher Introspection allows access to subjective data that can not be gained from traditional objective methods and enables the examination of experiences by the person that experienced them.

The researcher can continuously observe relevant personal experiences over very long periods. This increases the length of the research.

Researcher introspection allows for a more in-depth understanding of the emotions, experiences, and motives involved in the phenomenon being studied by mentally reliving, hypothesising, theorising, and retesting.

And lastly, researcher introspection allows for minimal ethical concerns.

Relevance

Researcher introspection is relevant to this project for two main reasons.

First, a lot of varied data has to be generated, among data of which the details are unknown at the start of the experiment. For these unknown situations to reveal themselves Grippy needs to be worn for long and varied amounts of time.

Second, much of the expected insights are subjective and need to be compared amongst itself. Which would be difficult in a situation where the experiences of multiple participants are compared.

By doing an auto-empirical experiment I can also solve a practical problem. Namely, the prototype can be quite finicky, and without proper care, it is expected that the prototype might stop working correctly. By being both the researcher and test person I will be able to immediately respond when the prototype malfunctions.

Wallendorf and Brucks (1993) describe four ‘weaknesses’ of researcher introspection. Two of these ‘weaknesses’ can be avoided with a more detailed and structured research method.

Data accuracy

Researcher introspection, and more specifically autoethnographies, are often conducted retrospectively. However, memories lose reliability over time. Therefore it is important to implement a structured way to descriptively record data while in the moment.

Additionally, extreme situations are more likely to be remembered and thus reflected upon. I believe that in this experiment this is not necessarily a bad thing. We explore the interaction with Grippy and are interested in the situations where it breaks, which are expected to be memorable. However, in the analysis, additional attention might need to be given to smaller experiences.

Data documentation:

When introspecting, researchers are likely to conclude according to ‘a series of undocumented recollections rather than a systematic and separately analysed recording of experiences.’ Because of this, it is often hard to evaluate the conclusions which are made.

By clearly linking the conclusions to the originating experiences, keen and interested readers can read the notes and can evaluate the conclusions made.

The other two ‘weaknesses’ described by Wallendorf and Brucks (1993) are inherent to researcher introspection.

Distance in data analysis:

There is a dispute about a person’s ability to scholarly observe him or herself. Some believe that because of the closeness of the researcher and the subject, generating a scholarly interpretation of phenomena is difficult. (Xue and Desmet, 2019) add that some make the argument that if the ‘observer self’ does not influence the subject matter, the ‘observer self’ has as much scientific grounds to make observations as a third-person observer would.

Generalisability

The data obtained from a researcher introspective is likely not generalisable to a larger population. This limits researcher introspection mainly to supporting or explorative research.

Implementation

I will make a log of comments in which I will log insights, feelings and experiences. This will take the form of a google form which will guide the researcher introspection.

I opted for written accounts over recorded ones. The reason for this is that I often am not in the situation to record audio while not removing me out of the ‘social’ situation. By writing on my phone I can keep myself in the situation and I can look around and listen to report environmental stimuli.

Appendix B3: Situation reports

Working

While working I had no problem noticing the Grippy signal. I was seated in the house living room with plenty of roommates walking around and talking to each other. I believe that I was not more focussed on the Grippy signals than if I were not working on my graduation project. Though I do not know this for sure.

Chatting outside

One of the first tests with Grippy was while I was sitting around the campfire with my roommates. I am writing this sometime after the event so take this report with some scepticism. I remember my roommates telling me that they did not notice I was pressing the button on Grippy when I received a signal. But rather noticed me picking up my phone to make notes. I was mostly sitting in the garden, talking and drinking beers.

I had no problems noticing the Grippy signals and felt comfortable. I did have to ‘reconnect” to the conversations after I made the notes on my phone. Often it was easier to wait for a few minutes until the conversation switched to a new topic.

I do not remember feeling anything when the signals came in. But during the early tests, I was also not actively trying to see if I felt stressed.

Gaming (Diablo 3)

Setup:
One thing I hear often is that it is very hard to get a hold of me when I am playing video games. Diablo 3 is an action RPG which when played at higher difficulties will kill your character when you are not paying attention. I was interested in whether I would notice the signal when playing this game, and how it would feel while having to stop in the middle of combat.

I sat at the dinner table with my roommates on their laptops around me. I was wearing headphones playing music and was mostly able to ignore the conversation my roommates were having. Though my roommates did distract me at times.

My left hand, on which Grippy is located, was still. My fingers were moving. Wearing Grippy as a glove did hamper my typing quite a bit and even caused some uncomfort after longer use. Pain much like early RSI. However, I didn’t notice the glove while playing. And I did not continually think of the Glove being there and or waiting for a signal.

The Grippy signals were very clear to me during playing. Even at the more eventful moments of the gameplay. I did get more and more stressed as I continued playing the game. There were times at which I was failing quite a bit. But I do not think this influenced my reaction time.

The Grippy signal also did not make me more stressed. If anything, it made me less stressed. I do not know the reason for this. It could be because I could succeed at something for a moment. Or take my mind off the game and draw me a bit back into reality.

While gaming, music did not seem to impact how noticeable the vibration was.

Also, the signal just after gaming felt harder to notice. I can think of two reasons:

Distractors came from more different sources

I was less focussed

I got more stressed throughout gaming and this impacted it

Cycling

Setup:
Cycling is the activity which is expected to be the hardest activity in which to notice the Grippy signal. The true stress test. I went cycling with both my roommate and parents separately. Mostly on bicycle-only roads, outside of urban areas.

Here activity, social conversation and many environmental vibrations/other stimuli came together. The first signal I noticed while slowing down at an intersection at which I had to go left. I didn't know how long it had been going but I was positive that I noticed it quite quickly.

Then later when I was cycling with my parents I did not pay any attention to the glove at all. I had been doing a lot of testing already and was quite used to the glove. At some point, I noticed 'something' and placed my right hand on the Grippy glove. After waiting for the pulsation signal to come again I noticed it was indeed going off. I pressed the button and stopped to record my findings. I expected it had been going for some time. Maybe even a minute or so.

After that, I lost a bit of confidence in noticing the Vibrations while cycling and I started to check the Grippy prototype with my right hand more often. Not much later I felt another signal, again with my right hand. At this moment I had my doubts about noticing the first signal as the second signal felt less than ten minutes later than the first. I stopped again to record my findings. But at this moment I was quite confident that I was not noticing signals while cycling. I was cycling with a headwind at the time.

At this point, I noticed I was paying much more attention to the glove than before. I was not always paying attention to it, but I had lost the trust I had when I started cycling. I believe I noticed the latter three signals in time. I also did not need to check the signal with my right hand anymore to confirm that there was indeed a stress alarm going on. I believe that the direction of the wind is the most likely explanation for the physical noticeability during cycling. The second half of the trip I had the wind in my back. However, this could also be explained by myself getting acquainted with the feeling of getting unconsciously better at separation bicycle vibrations and the Grippy vibrations.

The last signal I received was very clear to me, I was riding slightly downhill at the moment with the wind in my back. It could be that my hand was loose from my steering wheel. But even if it wasn't I was likely not putting any pressure on the steering wheel with that hand.

Cinema

I went to see an action film with another person to both test how the signal felt while watching a movie, and whether it would disturb people sitting next to me. The other person was sitting on my left. The Grippy prototype was located on my left hand.

The signals came in very clear, but not intrusive. I could not make notes during the movie, so reporting to Grippy was only a minor disturbance which I did not mind that much. The Glove was comfortable even after wearing it for three hours straight and did not bother me. I had no probing responding to the signals during the movie. The movie (The Gentlemen) has quite a lot of slow or quiet scenes. I can't recall what was happening when I received the signals.

Reporting did not draw me out of the movie, and the person I was with did not notice me repeating signals.

Walking in the mall

In the mall, you are very exposed to other people. Though I quickly forgot I was wearing a glove prototype, and if I received many stares because of it I did not notice it. There were moments at which the signal came at an inopportune moment. For example, one time I received a signal while I was changing into a shirt I was thinking of buying. First, the Grippy prototype got a little bit stuck in the sleeve, nothing major, but because I did not want to damage the already fragile prototype It took some time to get it through undamaged. While I was in the middle of that, the signal came in. While I was filling in the form, the shopkeeper came to check whether I liked the shirt. At this point, I was still busy and had to ask her to wait a little longer.

There was also a moment in which I was talking to someone who was telling me about headphones with active noise cancelling. I was currently wearing the headphones and with the assistant showing of the various features, I did not stop him to ask if I could fill in a form really quick.

The signal always came in clear and I had no problem responding to it. And I was able to find the time to fill in the form relatively soon every time. I did not have the feeling that people were treating me different because I was wearing Grippy. I received most of the signals when I was walking around or browsing stores, at those moments it felt like no intrusion at all, though having to stop in the middle of busy area’s where people had to keep 1,5 distance did bother me a little bit.

There was one signal that I only noticed slightly, even though my environment was not much different than the previous occurrences. Non trivially I had just (+/- a minute ago) had lost my debit card in one of my pockets and had been thinking about what I would have to do if I did not find it. I believe this is the most stressed I have been while wearing grippy. When the signal occurred I did not feel stressed anymore. So it could have nothing to do with it.

Calming down

At times I received a signal when I was calming/cooling down. For example, after cycling to my parents and when just finishing playing the game Diablo 3. During these situations, I felt the Grippy signal. This signal then often prompted me to stop the testing and to put away Grippy.

Cycling two

I went cycling a second time. The idea was that this time I would use the stronger vibration strength. Afterwards, I noticed this might have gone wrong but I will check.

I believe I noticed most signals immediately this time. I might have been more careful with it, or the higher signal strength helped. Grippy falling apart was an issue also. The prototype has seen a lot. I have to repeat it. I don’t believe it influenced the results.

Stopping to fill in Grippy form did not evoke negative feelings. It was just something that I had to do. Though, my father who cycled with me did leave early because it was too often.

I received a lot of signals. Early on I felt that it did make me a bit tired and annoyed, but later on, when I got used to it it did not bother me that much anymore. I believe that the first few were also quite close together compared to the signals later on in the trip.

This time I did not notice a difference in noticeability between back wind and headwind. Though most of the time I had to check with my right hand if something was going on. I quite liked this. This way I did not have to care about the signal at inopportune moments and I could address the presence of the signal when there was time.

Multiple times I thought I might be feeling a vibration but there wasn’t one. So I certainly was more aware that signals were coming. Also because of the shorter timeslot between signals. I felt that it sometimes took quite a while between signals. This would confirm the idea that things went wrong. And that I was not feeling a singular short interval signal sequence. But two (or more) long interview signal sequences.

From a signal sequence and code point of view, there was a lot wrong with this test, which I only noticed/thought of near the end of the trip. Maybe even at the last received signal when I thought I received two close together. I will check the logs for data and get able to tell what was going on.

I believe my response data is still quite relevant. I do believe I was more attuned to the signal than I was the first cycling trip. But I am not sure if that is a bad thing.

Graduation meeting

Grippy did not influence me, though I did want to keep Grippy of the screen. Even though I knew the others were working on the same project. It maybe is part of not wanting to draw attention to myself. At times I did forget I was wearing Grippy. And it did not negatively influence the meeting for me.

Appendix B4: Situation insights

Researcher introspection:

After each activity, a short description will be given of the situation. This description will likely emphasise moments that are clearly remembered, and thus triggered a stronger reaction. Additionally, after each vibration signal, a comment form is filled in. The statements made in these descriptions and comments are extracted. And put in a format.

Statements will have a form of:

While [activity] (in [location]), I found that [insight]

or

While [activity] (in [location], I hypothesised that [hypotheses])

These statements will be grouped per subject and from these grouped statements subjective insights will be drawn. These subjective insights are then compared to the quantitative results of the form and glove.

Summary

- Extract statements from reflective descriptions
- Extract statements from the comments
- Group statements
- Create subjective insights
- Evaluate the subjective insights with the quantitative data

Insights

First, the signals are grouped in broad categories like noticing Grippy. Afterwards, distinctive propositions are made argumentation by the statements. Here, the absence of negative statements is interpreted as positive. E.g. If no statements state difficulties noticing Grippy in a certain situation, we interpret that as Grippy being noticeable in that situation.

Subjective Finding

Relevant statements from comments and situation reports

- Support from data

Noticing Grippy

I had no problems noticing the 40% vibration signal in most situations.

[R] While working I found that I had no problem noticing the Grippy signal.
[R] While sitting outside I found that I had no problem noticing Grippy's signals.
[R] While gaming I found that the Grippy signals were very clear.
[R] While watching a movie in the cinema I found that Grippy's signals were very clear
[R] While trying on clothing in the mall I found the signal was clear and unintrusive
[R] While walking in the mall I found the signal was clear and unintrusive
[C] While making lunch I found I did not remember noticing a signal I did respond to

[C] While working I found that I immediately noticed the signals
[C] While calming down from cycling I found the signal was very clear
[C] While thinking about code I found I felt the signal clearly
[C] While receiving a signal earlier than expected while cycling I found I felt Grippy's signal clearly
[C] While receiving an unexpected signal I found it to be clear but faint.
[C] While gaming I found music did not impact the noticeability.

- Data supports this, only signals while cycling were missed

When calming down from stressful situations the vibration signals felt fainter

[R] While calming down from a stressful situation in the mall I found that I only slightly noticed the signal.
[C] While calming down from gaming the signal just after gaming felt harder to notice
[C] While recovering from a stressful situation I found that I barely noticed the signal.
[C] While calming down from gaming I hypothesised finding it harder to notice a signal because I was less focussed
[C] While calming down from gaming I hypothesised finding it harder to notice a signal because there were more varied distractions
[C] While calming down from gaming I hypothesised finding it harder to notice a signal because I had become stressed.

- Data says that response time is fast in these situations

In specific circumstances, the signal is briefly less noticeable

[C] While outside hearing a bell tower I found that I double-checked the vibration signal.
[C] While eating cereal I found that it took me some time to realise what the sensation was
[C] While eating cereal I found that bringing the bowl to my mouth hid the signal slightly
[C] While working outside I found that a small breeze hid the Grippy vibration when I wanted to double-check

- These moments are above average response time.

I missed some signals at 40% vibration strength when cycling

[R] While cycling I found that I noticed signals when they were already going off
[R] While cycling I found that I likely missed some signals
[R] While cycling I found that I noticed the last three signals in time
[R] While cycling the second time I found that I immediately noticed most signals
[R] While cycling I hypothesised that the direction of the wind could explain the ease at which vibrations are noticed
[R] While cycling I hypothesised that experience recognising Grippy's signal could influence my better performance.
[R] While cycling the second time I hypothesised I might have been focussing more.
[R] While cycling the second time I hypothesised I might have become better at recognising the signal.

- I missed more signals than I believed

When cycling, I needed my right hand to check if a signal was going off

[R] While cycling I found that I used my right hand to check whether signals were real.
[R] While cycling I found that I did not need to check the last three signals with my right hand.
[R] While cycling the second time I had to check with my right hand most of the time.
[C] While cycling I found that I repeatedly checked Grippy when there wasn't a signal.

- Data can't say anything about this

The wind might influence noticeability

[R] While cycling I found that noticing the signals with backwind was easier
[C] While working outside I found that a small breeze hid the Grippy vibration when I wanted to double-check
[R] While cycling the second time I found that head or back wind did not appear to make a difference.

- Cycling with wind vs Cycling without wind. We can't say this for sure. Certainly not the only effect.

The 100% vibration strength signal is easier to notice than the 40% signal.

[R] While cycling I found that I noticed signals when they were already going off
[C] When cycling I found I noticed the 100% vibration strength signal immediately.
[C] When switching back from the 100% to 40% signal I found it was noticeably weaker

Signal response

I had no problems responding to signals in most situations

[R] While gaming I found that stress did not influence my reaction time.
[R] While watching a movie in the cinema I found that I had no problems responding to the signals
[C] While someone was talking directly to me I found it appropriate but uncomfortable to press the button.
[C] While talking to a stranger I found I had no problem pressing the button
[C] While walking in the mall I found that I pressed the button before I got an idea of how hard I felt the signal.
[R] While gaming I found that stress did not influence my reaction time.

- Data supports this

I took my time responding to the 40% signal

[R] While cycling the second time I found that I took the time to safely answer Grippy and fill in the form.
[C] While working I found that one time I found that I took longer to respond because I wanted to check if the signal was continuous.
[C] While playing Mario kart I found I did not respond to the signal immediately
[C] While talking I found that I took my time to respond to the signal
[C] While receiving an unexpected signal I found I took longer to respond
[C] While eating cereal I found that even though I was confident I felt Grippy, I waited for the continuous signal to come back to be sure

- Data supports this

The strong signal prompted me to react faster

[C] When cycling I found that the 100% vibration strength signal made me want to respond fast.

I twice had difficulty finding the button

[C] While in the dark I found that I had difficulty finding the button
[C] While recovering from a stressful situation I found I had difficulty finding the button

- Data supports this, however, this did not greatly influence response time

There were no problems with having to use the right hand to respond to signals

- Data supports this

Form response

In most cases, I had no problems filling in the form

[R] While walking in the mall I found that I could fill in the form relatively soon.
[R] While cycling the second time I found that I took the time to safely answer Grippy and fill in the form.
[R] While cycling the second time I found that stopping to fill in Grippy did not evoke negative feelings.

- The form was only filled in 70% of the time

While texting I would finish my message if I was texting before filling in the form

[C] While typing a message I found that I finished the message before filling in the form
[C] While texting in public transport I found I finished texting before filling in the form.

- Data has nothing on this

Social context influenced how soon I would fill in the form

[R] While someone was helping me in the mall I found that I put off filling in the response form.
[C] While someone was talking directly to me I found that I hesitated to fill in the form
[C] While someone was showing me something I found that I might have skipped taking action if it was not documented
[R] While walking in the mall I found that having to stop in a busy street bothered me.

- We see that strangers greatly influence form response time

Discretion

Pressing the button is a discrete interaction

[R] While sitting outside I found that my roommates did not notice me pressing the ‘challenge button’.
[R] While watching a movie in the cinema I found that the person I was with did not notice me responding to the signals.
[R] While in the mall I found the signal was discreet
[C] While someone was talking directly to me I found it appropriate but uncomfortable to press the button
[C] While talking to a stranger I found I had no problem pressing the button.

- Data has nothing on this

Filling in the form is not a discrete interaction

[R] While sitting outside I found that my roommates noticed me picking up the phone to take notes.
[R] While trying on clothing in the mall I found I had to ask for more time because I received a signal.

- This could go along with stranger form response time

Wearing the Grippy glove does not feel discrete, but I have had no negative experiences

[R] While in the mall I found that people were not treating me differently.
[R] While in a graduation meeting video call I found that I wanted to keep Grippy off-screen.

- Data has nothing to add

Signal comfort

I felt comfortable responding to Grippy’s signals in most situations

[R] While sitting outside I found that I was comfortable responding to Grippy’s signals.
[R] While talking outside I found that I did not have strong feelings towards Grippy’s signals.
[R] While gaming I found that Grippy’s signal did not make me more stressed.
[R] While trying on clothing in the mall I found the signal was clear and unintrusive
[R] While walking in the mall I found the signal was clear and unintrusive.

- No data available

The signal triggered a relaxed response

[R] While cycling I found that I noticed signals when they were already going off
[R] While cycling the second time I found that I did not have to care about the signal at inopportune moments.
[C] While cycling I found that the signal was not stressful.

- Variance is response time supports this

Checking Grippy with the right hand is liked

[R] While cycling the second time I found I liked the action of checking Grippy with my right hand.
[C] While cycling I found that pressing the button felt natural.

- No data

10-25 minutes in between signals is fine, 5-15 minutes is too short.

[R] While cycling the second time I found that one signal every seven minutes was annoying at first.

- No data.

In some very personal social situations, pressing the button can feel uncomfortable

[C] While someone was talking directly to me I found it appropriate but uncomfortable to press the button.

- We actually see faster response times.

There are moments where the signal can create frustration

[C] While playing Mario kart I noticed I was frustrated with the vibration signal.

- Not enough data.

The 40% vibration signal is preferred over the 100% signal

[C] When testing I found that the 100% signal was very intense.

- No data.

Glove comfort

Grippy can be worn for multiple hours without problems

[R] While watching a movie in the cinema I found that Grippy was comfortable to wear for two hours.

- It might be interesting to look at the average, longest and shortest duration.

The user can get used to the feeling of Grippy on the arm.

[R] While in a graduation meeting I would forget I was wearing Grippy

- No data

Though Grippy's bulk does limit the user's freedom.

[R] While trying on clothing in the mall I found Grippy got stuck in my sleeve.
[C] While cycling I found that Grippy made me react slower to the feeling that I should take off my jacket because of heat.

- No data

Sweat can build up under Grippy

[R] While cycling I found that my hand was getting sweaty

- No data

Behaviour

Checking faint signals with the right hand

[R] While cycling I found that I used my right hand to check whether signals were real.
[R] While cycling the second time I had to check with my right hand most of the time.
[C] While cycling I found that I still checked with my right hand, even though I was sure Grippy was sending a signal.
[R] While cycling the second time I found I liked the action of checking Grippy with my right hand.

- No data

Focus / Disruption

Signal low impact in most situations

[R] While watching a movie in the cinema I found that Grippy's signals did not let me lose focus.
[R] While watching a movie in the cinema I found that I can't remember which scenes I received signals.
[C] While walking in the mall I found that I pressed the button before I got an idea of how hard I felt the signal.
[C] While making lunch I found I did not remember noticing a signal I did respond to

- No data

No disruption outside of signals in most situations

[R] While cycling I found that at first, I did not pay any attention to the glove.
[R] While in a graduation meeting I would forget I was wearing Grippy

- No data

Filling in the form was of high impact in social situations

[R] While talking I found that I had to reconnect to the conversation after making notes.
[R] While trying on clothing in the mall I found I had to ask for more time because I received a signal.
[R] While cycling the second time I found that stopping to fill in Grippy was very disruptive for the people I was with.

- We see the form being filled in less when other people are present

Higher attention to Grippy when missing signals is expected.

[R] While cycling I found that I checked Grippy often after I knew I missed a signal.
[C] While cycling for the second time I found that I repeatedly checked Grippy when there wasn't a signal.

- We see Grippy response time while cycling go down

Other insights

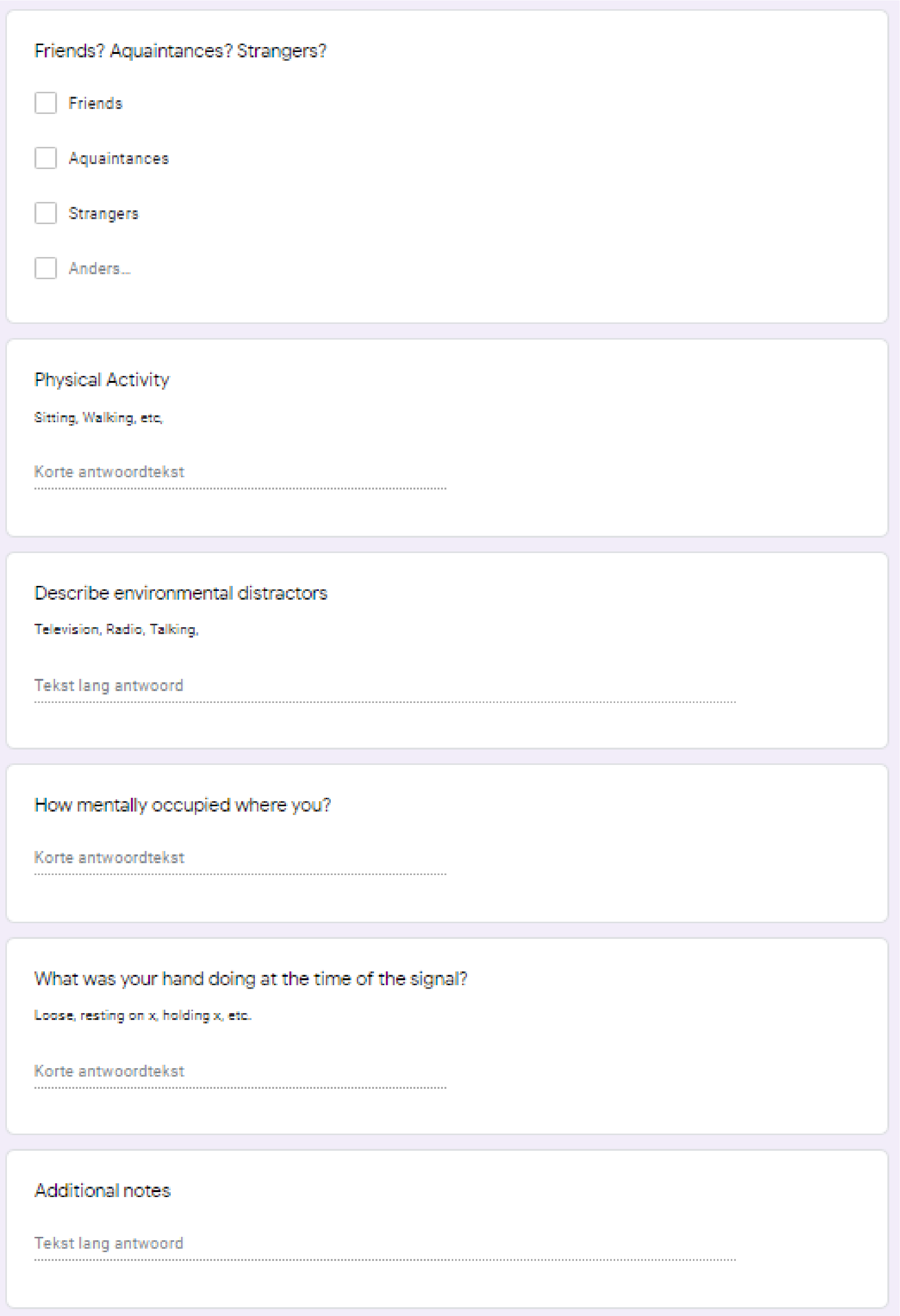
Situational qualities

[R] While working I found that I was not focussed on the graduation project.
[R] While gaming I found that I was getting more stressed over time
[C] While cycling I found that I was thinking about my graduation often.
[C] While in the mall I found I was not stressed
[C] While walking to another train I found that I was a bit stressed.

Prototype and test setup

[R] While cycling the second time I found that Grippy would occasionally fall apart.
[C] While working I found that I had not turned off all signals and Grippy would also send non-continuous signals
[C] While cycling I found that notes are likely less elaborate than spoken notes

Appendix B5: Situation qualities logging form



Friends? Aquaintances? Strangers?

☐ Friends

☐ Aquaintances

☐ Strangers

☐ Anders...

Physical Activity

Sitting, Walking, etc,

Korte antwoordtekst

Describe environmental distractors

Television, Radio, Talking,

Tekst lang antwoord

How mentally occupied where you?

Korte antwoordtekst

What was your hand doing at the time of the signal?

Loose, resting on x, holding x, etc.

Korte antwoordtekst

Additional notes

Tekst lang antwoord

Appendix C: Software changes

Appendix C1: Before experiment 1

There is an android application build with Flutter which can communicate with the glove via Bluetooth. The glove measures the pressure sensor data and sends it to the android application every five seconds.

The glove can run three preset vibrations that differ in waveform, length and intensity. These are the ‘challenge signal’, the ‘inactivity reminder’ and the ‘stress alarm’.

Signal sequences

Software signal sequences will be used that send vibration signals at preset intervals to the glove. The participant must not know when vibration signals will happen, and the researcher will not be close enough to send manual vibration signals to the participant. The intervals between the signals will be randomly generated and will be unknown to the participants.

In each signal sequence, the android app will send five signals at preset intervals to the glove, each representing a vibration pattern and intensity. The intervals between the signals are chosen randomly but individual signal sequences are the same for each participant. The vibration strength will go up in increments of 20% from 20% to 100% during each signal sequence.

The software signal sequences will be started through the grippy phone application. There will be five signal sequences in total. One for each task and one for the baseline measurement. The participant is requested to start a signal sequence at the start of each task as directed by the researcher.

The Grippy application home screen will show a button each signal sequence as can be seen in Figure 38. These buttons are labelled A-E and should be pressed alphabetically. The researcher will also call out which button needs to be pressed. Lastly, the buttons will be disabled once pressed. This way the participant does not accidentally follow the same signal sequence twice.

Signal selection over BlueTooth

As only ‘characters’ can be sent with the current Bluetooth communication implementation of Grippy. Only a limited amount of information can be sent, without spending additional time writing a custom buffered reader. In the original Grippy that was not a problem, as there were only 4 preset signals which could easily be represented by the characters ‘1’, ‘2’, ‘3’ and ‘4’.

However, for the signal sequence implementation, and easy changes we need to be able to send both the signal pattern and signal strength over BlueTooth.

Figure 38: Android application

ASCII characters can represent the integers 0 to 123. For readability, we can convert two-digit integers to a single ASCII character and then send that character. For example, Signal pattern 6 at intensity 3 would be stored as 63 and then converted to ASCII. Then the character ‘a’ would be sent to the Arduino over BlueTooth where it would be converted back and executed.

Arduino code:

```
void setVibrationPattern(char cmd){
  int num = cmd;                    //This converts the ‘a’ back into 63.
  int signal pattern = num/10;      //This will round down due to how integer division in C++ works.
  int signal intensity = num%10;
}
```

Then by letting the intensity variable influence the selection of the waveform, we can vary the strength of the signal we send.

Similar vibration patterns at varying intensity

We need Grippy to send signals of which the main quality difference is the vibration intensity. However, we also want to avoid false positives from the users believing when they heard a signal Therefore we will send a vibration pattern to the users which consist of multiple short pulses and differ from eachother like in Figure 39.

The Adafruit vibration motor controller of Grippy works with preset waveforms. There are 127 waveforms in total. Presets 47-51 represent buzzes from 20% intensity to 100% intensity. These will be used for the patterns because the vibration strength is the only difference between them. The arduino code snippet describing one pattern will look as follows:

Arduino code:

```
void patternA(int intensity){
  int waveform = 52 - intensity;
  drv.setWaveform(0, waveform);
  drv.setWaveform(1, 123);
  drv.setWaveform(2, waveform);
  drv.setWaveform(3, 123);
  drv.setWaveform(4, waveform);
  drv.setWaveform(5, 0);
  drv.go();
}
```

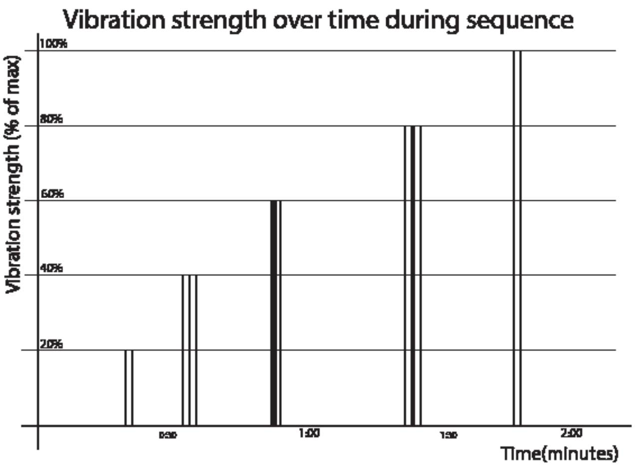


Figure 39: Vibration strength during sequence

The vibration motor controller is set up so that it allows us to chain a set of vibration signals. Unfortunately, we cannot create silence this way. However, by choosing preset waveform 123 (Smooth hum 6: “10%”), we create moments of very light vibrations in between the buzzes. This hum is slightly noticeable, especially on the softer buzzes.

This problem could also be resolved by bypassing the vibration chaining functionality and having the Arduino start multiple short vibration signals with set intervals between them. This method was not chosen due to time restraints.

With seven usable digits, this results in 128 different vibration patterns though many are very similar. The following five patterns were chosen as they were assumed to be easy to distinguish.

Patterns: (X means on, 0 means of)

A: [X,0,0,X,X,X,0]
B: [X,0,X,0,X,0,X]
C: [X,0,0,X,0,0,X]
D: [X,X,0,0,X,X,0]
E: [X,X,X,X,X,0,0]

More direct pressure sensor feedback

The original software implementation of Grippy lets the users input their stress levels by pressing on the pressure sensor with different levels of pressure. Then Grippy will send a pattern back with one, two or three buzzes respectively for each vibration intensity.

However, because the patterns have to finish before Grippy updates, this feels quite sluggish. Especially because the vibration signal continues a bit after the sensor is no longer being pressed. This feedback is not helpful when the user tries to input patterns of presses and pauses. Instead, the user just needs to know whether the pressure sensor is pressed or not.

I removed the stress level recognition implementation of the pressure sensor and replaced it with a continuous vibration that would go off when the user would press the pressure sensor. The threshold for this was put at 700. Which was previously the level from which a light press would be recognized.

This made the pressure sensor feel more responsive and allowed the user to easily repeat patterns using the pressure sensor.

Logging improvements

Previously, the software logged data every second. I removed this time restriction and I made the software only log when it receives signals over Bluetooth or measures changes in stress level. This way we still keep our logs to a minimum, while being able to log even rapid presses.

Also, logging was disabled when the prototype did not measure heart-rate. I removed this restriction as the heart rate measurement is not very reliable and this was cause for problems.

Appendix C2: Before experiment 2

Glove

For the first experiment, a system was implemented with which the timing, vibration strength and pattern of a signal could be sent from the phone application. Therefore, no changes needed to be made to the Arduino implementation of the glove.

Phone application

A new signal sequence was created at which five signals would be sent with a set interval between 7 and 15 seconds and with increasing intensity. The pattern used for all the signals is a single note which is held for a second.

The differences between this signal sequence and the signal sequences used in experiment 1 are the shorter interval and the fact that only a single pattern is used.

Appendix C3: Before experiment 3

For the experiments unanticipated vibration signals with unanticipated patterns needed to be sent. Changes were made to the glove hardware to hardcode the various patterns and allow for more flexible commands. The functionality to send vibration signals at intervals has been added to the android phone. The intervals and the patterns of vibration signals can be preset or generated pseudorandomly within boundaries.

The Grippy map has been replaced by a button interface with which the application can be controlled. Additionally, the user can use the interface to give additional context about the situation he or she is in.

Signal sequence

The goal of the signal sequence is to send vibration signals at moments where the researcher - introspector will not expect them. The time between signals can range between 10 and 25 minutes to make the signal come at an unexpected time. A minimum delay of 10 minutes is there to avoid signal fatigue. In less than 10 minutes the likelihood of the researcher still being in the same state is increased, therefore also resulting in less novel data. A maximum delay of 25 minutes is set to ensure that at least one signal will arrive during planned limited duration high distraction scenarios. Such as heavy exercise and or playing the piano.

Sub-second accuracy

Previously, the timestamps of the various events and button presses of Grippy were logged in seconds. To more accurately measure the time between the signal sent and the button click response we need to log the timestamps with more detail.

In the original implementation, the Arduino in the Grippy glove recorded the timestamp of events and would send that to the android application. This gives additional accuracy as the time it takes to send data over BlueTooth can vary by +/- 100 milliseconds.

The standard data-time implementation of Arduino does not log daytime milliseconds. To simplify how the code handles logging data, the phone application time would be used to record the timestamps.

As transferring the data over BlueTooth also requires time, this is only accurate up to 200 milliseconds. However, this accuracy will increase as we average over multiple measurements and we are not as interested in individual differences in response time.

Glove

The state machine of the Grippy glove was also revamped. In the original state machine, all functions were given individual states, this included both the functions which log data and check for state changes.

However, both logging and checks for state changes also showed up in other states to achieve a functional code. The state machine was streamlined and both the ‘logging’ and ‘checking for state changes’ functions will now run parallel to the state machine. This way adding new states and transitions becomes easier.

Continuous signal

A continuous signal was created that could be started over BlueTooth and stopped by pressing the button on the back of Grippy.

Because the vibration strength is relevant to the test, the buzz sound from the first experiment was used to create a pattern. Because a rhythm that swings a little bit was assumed to be less stressful, a slightly irregular pattern was chosen. Bzz - Bzz - BzzBzz - Bzz.

Interface options

On the phone interface, additional options were added. Two signal sequences, one with the normal duration and one with half the normal duration for situations that are unlikely to last 25 minutes.

And a toggle with which the vibration strength of the signal sequence can be switched between 40% and 100% intensity. The 40% vibration strength signal sequence was used in most of the testing. When the 40% vibration strength signal was not noticed reliably in a certain situation, the 100% vibration strength signal sequence was used to see if a higher vibration signal strength could solve this.

DESIGN FOR our future

TUDelft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

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

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

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

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

STUDENT DATA & MASTER PROGRAMME

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

family name -van der Smagt

initials - given name -Mark

student number -

street & no. -

zipcode & city -

country -

phone -

email -

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

IDE master(s): ★ IPD ○ DfI ○ SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ○ Honours Programme Master

specialisation / annotation: ○ Medisign

○ Tech. in Sustainable Design

○ Entrepeneurship

SUPERVISORY TEAM **

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

** chair -Marco Rozendaal dept. / section: -

** mentor -Alessandro Bozzon dept. / section: -

2nd mentor

organisation:

city: country:

comments (optional)

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

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

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

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair -Marco Rozendaal date - - signature

CHECK STUDY PROGRESS

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

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

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

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

○ YES all 1st year master courses passed

○ NO missing 1st year master courses are:

name ______ date - - signature ______

FORMAL APPROVAL GRADUATION PROJECT

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

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

Content: ○ APPROVED ○ NOT APPROVED

Procedure: ○ APPROVED ○ NOT APPROVED

comments

name ______ date - - signature ______

Initials & Name - -van der Smagt Student number -

Title of Project Designing a system to personalise interaction for a smart wearable for str

Designing a system to personalise interaction for a smart wearable for str
project title

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

start date 02 - 03 - 2020

25 - 11 - 2020 end date

INTRODUCTION **

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

Designing a system to personalise interaction in a smart wearable for stress recognition.

Grippy is a wearable system that could help people to know their limits of dealing with stress. And warn the user when a stressful situation is imminent. When the user is experiencing stress, the user will be asked if he or she is “OK?”. The user can send signals indicating the level of stress he or she experiences and, by doing that, define locations perceived as “stressful”. The user can then avoid the location, or go back to those locations to overcome the stress via a self-training session.

The wearable system is composed of a glove and a phone application. The user can report his or her stress levels by balling his fist at varying strength. The stressful locations and challenge events will be shown in forms of an annotated map on the phone. Grippy will warn the user the next time he is near an area where stress has been reported in the past, and encourage the user to go for a “challenge”, i.e. a self-training session. At this stage, Grippy is a simple state-machine.

The signal that indicates rising stress and alert’s the user is an important part Grippy. Currently, the signal is divided into two different reminders. The first alert that will trigger at high heart rates and is used to identify new stressful situations, and a second alert that will trigger based on location as is meant to warn the user about possible stress and encourage the user to ‘challenge’ himself.

However, preliminary testing of the prototype shows that preferences differ from user to user. At times users will appreciate these signals, and at other times find them annoying. Location-based stress alerts are often incorrect when the user is passing by, or entering at a different time of day. Some users might also miss signals send by the glove.

Whether a situation is stressful is not solely related to the location. The social context also has to be taken into account. It is assumed that artificial intelligence can help personalize Grippy to better tailor this signal to the situation of the user.

space available for images / figures on next page

Initials & Name - -van der Smagt Student number -

Title of Project Designing a system to personalise interaction for a smart wearable for str introduction (continued): space for images

TO PLACE YOUR IMAGE IN THIS AREA:
- **SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER**
- **CLICK AREA TO PLACE IMAGE / FIGURE**

PLEASE NOTE:
- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
- **NATIVE IMAGE RATIO IS 16:10**
- **IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN**

image / figure 1:

TO PLACE YOUR IMAGE IN THIS AREA:
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- **CLICK AREA TO PLACE IMAGE / FIGURE**

PLEASE NOTE:
- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
- **NATIVE IMAGE RATIO IS 16:10**
- **IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN**

image / figure 2:

PROBLEM DEFINITION **

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

An important first step is for the user being able to notice the signals of Grippy. Setting these signals to maximum strength will likely be inappropriate is most situations. Therefore this project will attempt to adapting the actuator signal of Grippy to be appropriate at the situation the user is in.
The Grippy prototype is able to measure heart rate, acceleration and the pressure input of the user. The phone application can be used to obtain the GPS coordinates, time and date.
The varying situations in which the user might use the Grippy product need to be identified. Additionally, the current situation the user is in has to be made available to Grippy. This could be done by user self-reporting, data recognition or a combination of the two.

ASSIGNMENT **

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

Design a system that can adapt the strength of the vibration motor based on the situation the user is in. In a way such that the strength of the vibration motor is noticeable but appropriate for the user. To develop knowledge and understanding of personalising user-product interaction in autonomous smart wearables.

First, the different situations users are in while using the product need to be identified and a hypothesis of what kind of signal would be appropriate when has to be made.

Then the required inputs and outputs of the model need to be mapped out. For the inputs: This will involve which data will be collected, how it will be processed and finally how it will be presented to the system. In particular, how the user will be able to provide feedback.

For the output: this will involve whether the signal will change in pattern, length and/or change with intensity.

Next, a model will be designed incorporating all these design decisions. This model should allow Grippy to start from a base assumption of appropriate signal strength but should personalise the interaction over its use if needed.
After the model is complete, a test will be designed to evaluate the functioning of the model.

Based on the requirements of the test, the model will to be incorporated into the prototype. This will involve writing additional functions for the Phone and Arduino applications and if necessary adding additional input and/or output.

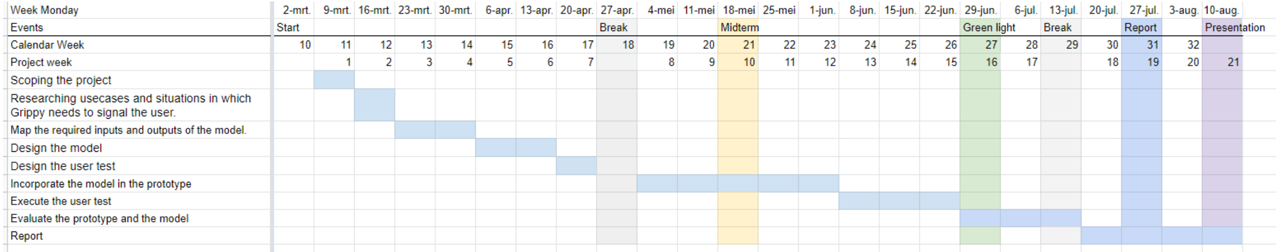
Lastly, the prototype will be user tested and evaluated.

PLANNING AND APPROACH **

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

start date 2 - 3 - 2020

25 - 11 - 2020 end date



Week Monday	2-mrt.	9-mrt.	16-mrt.	23-mrt.	30-mrt.	6-apr.	13-apr.	20-apr.	27-apr.	4-mei	11-mei	18-mei	25-mei	1-jun.	8-jun.	15-jun.	22-jun.	29-jun.	6-jul.	13-jul.	20-jul.	27-jul.	3-aug.	10-aug.
Events	Start								Break			Midterm						Green light		Break		Report		Presentation
Calendar Week	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
Project week		1	2	3	4	5	6	7		8	9	10	11	12	13	14	15	16	17		18	19	20	21
Scoping the project		■																						
Researching usecases and situations in which Grippy needs to signal the user.			■																					
Map the required inputs and outputs of the model.				■	■																			
Design the model						■	■																	
Design the user test								■																
Incorporate the model in the prototype										■	■	■	■	■										
Execute the user test															■	■	■							
Evaluate the prototype and the model																		■	■	■				
Report																					■	■	■	■

https://docs.google.com/spreadsheets/d/1gJ6MQIq_c8FyzbWTOxb9_lXrZDWoYbMHc0lVfNWaN8I/edit#gid=0

MOTIVATION AND PERSONAL AMBITIONS

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

I am interested in training artificial intelligence.
I am interested in labelling data in a meaningful way.
I want to show that I am competent at functional programming.
I want to show that I can plan a project with the aim to get fast results.
I want hands-on experience designing with a physical prototype in mind.

FINAL COMMENTS

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