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Benachrichtigungen mittels Vibrotaktiler Signale

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FAKULTÄT FÜR !NFORMATIK
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Notifications via Vibrotactile Signals

DIPLOMA THESIS

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in

Software Engineering and Internet Computing

by

Ludwig Werzowa, BSc.
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Wien, 26. Jänner 2020

Ludwig Werzowa

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Kurzfassung

Benachrichtigungen sind in der heutigen Zeit allgegenwärtig, wenn auch nicht gänzlich unproblematisch. In dieser Arbeit wird vorerst untersucht, welche Auswirkungen die für die heutige Zeit üblichen Benachrichtigungen auf uns haben. Studien sprechen von einer Informationsüberlastung, die zu negativen Auswirkungen führt. Es werden beispielsweise Zusammenhänge zwischen Unterbrechungen, verringerter Aufmerksamkeit und sogar geringerer Lebensqualität als Resultat genannt.

Durch subtilere Mitteilungsmethoden, wie Vibration, können diese negativen Auswirkungen abgeschwächt werden. Der weitere Fokus dieser Arbeit liegt in der Erforschung von Vibration als Mittel, wichtige Information zu übermitteln. Es wird den folgenden Forschungsfragen nachgegangen: Welche Information kann mittels Vibration übertragen werden, ohne ein visuelles Display zu benötigen? Welche Parameter können verwendet werden, um Vibrationssignale zu erzeugen, die für Menschen gut unterscheidbar sind? Auf welche Weise kann ein vibrierendes Armband Kommunikation aufwerten?

Als Methodik zur Beantwortung der Forschungsfragen wird ein gemixter Ansatz aus qualitativer und quantitativer Forschung betrieben. Zudem wird Prototyping und ein benutzerzentrierter Ansatz angewandt, um ein vibrierendes Armband zu entwickeln.

Mittels Anwendertests wurde belegt, dass durch Vibration Nachrichten mit unterschiedlichen Dringlichkeitsstufen erzeugt werden können und dass diese von Testpersonen erkannt und unterschieden werden können. Weiters stellte sich heraus, dass ein vibrierendes Armband positiven Anklang findet, insbesondere wird es in lauten oder leisen Umgebungen als nützlich empfunden. Unerwartet waren Unterschiede in der Wahrnehmung der Intensität der Vibration zwischen weiblichen und männlichen Testpersonen. Zudem wurde festgestellt, dass bei den ältesten Testpersonen eine signifikant schlechtere Wiedererkennungsrate von Vibrationsmustern vorlag.

Abstract

These days notifications are part of our everyday lives, although they are not without problems. First off, there will be an examination of the effects lying in the most common types of notification of our current times. Studies mention attention overload leading to negative effects influencing us daily. There have been found to be correlations between interruption caused by notifications, leading to inattention and further, even decreased satisfaction in life.

By using more subtle forms of notification, such as vibration, these negative effects can be lessened in severity. The further focus of this thesis explores vibration as a means to transmit information. The following research questions will be examined: Which information can be conveyed via vibration without relying on a visual display? Which parameters can be used to produce vibration signals that are easily distinguishable for humans? In which way does a vibrating bracelet enhance communication?

To answer these research questions, a mixed-methods approach consisting of both qualitative and quantitative research has been utilized. Additionally, prototyping and a user-centered approach have been used to develop a vibrating bracelet.

User tests showed that vibration notifications with different urgency levels could be produced and that test persons were able to reliably identify and distinguish them. Test users showed a positive response towards a vibrating bracelet, and consider it especially useful in noisy or quiet environments. Some unexpected findings included a difference in the perceived intensity of the vibration between female and male test persons. In addition, there was a significant difference in recognizing vibration patterns connected to the test persons' ages.

Contents

CHAPTER 1

Introduction

1.1 Problem Definition

Notifications are very common these days, even though they are not without problems. Studies show that notifications cause interruption, which leads to inattention and a number of secondary negative effects [1]. Other studies found out that just silencing a phone does not dramatically decrease the time it takes test persons to react to notifications [2]. The reason seems to be that users are afraid to miss important information [1, 3].

Vibration functionality for mobile phones is common today. It mainly serves the purpose of supplementing ring tones and all kinds of notifications from mobile phones. It is especially useful in cases where notification via the audio channel is not an option, such as in noisy environments or in quiet environments, when phones must be muted.

More recently, vibration has also been used in various wearable devices including bracelets. There have been a number of fashionable bracelets, mainly with a fitness focus, such as the Jawbone UP24 [4, 5] or the Fitbit Flex [6] that offer vibration features for alarms or fitness notifications. There are also developments for bracelets that have a wider range of functions which assist with communication: The TapTap [7, 8] bracelet is a device that lets two individuals connect to each other by transmitting each touch to the bracelet from one person to the other person's bracelet as a vibration signal. MEMI [9, 10] has a different approach. It signals incoming calls or messages of selected persons via vibration.

In regards to transmitting information, this thesis will explore ways to use vibration functionality for more complex communication while minimizing the need for a visual display.

It is important to note that in this context vibration will be used to communicate very specific messages in specific situations. Rather than a complete morse alphabet, meaningful, predefined messages will be discovered and tested. A vibrating bracelet prototype shall be developed, including a corresponding iOS application and a Java back end.

1.2 Expected Results

The result of this work will consist of a theoretical part that will answer research questions, a practical part in form of the development and implementation of a discrete and open notification system on a prototype level, and an evaluation and analysis part. The development and implementation of this system will be documented.

1.2.1 Research Questions

Below is a list of interaction-related research questions within the study of notification which will be answered in this thesis:

1. **Which information can be conveyed via vibration without relying on a visual display?**

   That will be the main question to be answered by this thesis and will consist of several sub-questions. An evaluation of practicality for using vibration signals only will be part of this question, as well as the exploration of boundaries of a purely vibration-based communication approach. My goal is to evaluate whether the following information can be conveyed within one vibration signal: Specific, predefined messages, the urgency of messages, and additional information, such as being able to identify a sender.

   Each point will be evaluated for feasibility in a first step. In a second step these three points will be combined into one vibration signal.

2. **Which parameters can be used to produce vibration signals that are easily distinguishable for humans?**

   Various parameters for vibration functionality will be evaluated and tested, such as the intensity of vibration, frequency, and length. Studies about distinguishability of vibrotactile signals [11] will be taken into consideration.

3. **In which way does a vibrating bracelet enhance communication?**

   To answer this question, current forms of notifications will be analyzed for their problems and weaknesses. Studies concerning negative consequences, such as attention overload [3, 12] or interruption [1] will be analyzed. Design specific questions regarding vibrating bracelets [13] and vibration perception [14] will be considered.

1.3 Structure of the Thesis

This thesis consists of a theoretical part, a practical part, and an evaluation. In the theoretical part, Chapter 2 *Notifications* will review problems and implications related to notifications. Possible solutions to avoid negative effects will be presented here as well.

Chapter 3 *Vibration* is all about vibrotactile signals and deals with two main topics: Where on the body vibration is perceived best, and how urgency can be classified through different vibrotactile signals.

The practical part starts with Chapter 4 *Methodology and Approach*. For evaluation purposes, a mixed-methods approach involving both quantitative and qualitative research has been chosen. A user-centered approach has been used in combination with prototyping to develop a vibrating bracelet.

Furthermore, Chapter 5 *Technical Implementation* outlines the development of the vibrating bracelet. After an introduction and the description of hardware parts, the programming of the individual components will be outlined. It will be described, how the three different programming languages of the components communicate with one another.

Chapter 6 *Hypotheses and User Tests* marks the start of Part III, the evaluation. First, hypotheses will be described, which will be evaluated later on. Afterward, the culmination of all previous information leads to the definition of the user tests.

Chapter 7 *Result Evaluation* shows an objective listing of results from the questionnaire. Charts, tables, and word clouds will be used to make the results of the questionnaire more easily digestible.

Finally, in Chapter 8 *Analysis*, the hypotheses from before will be evaluated for their validity. The thesis ends with a section about lessons learned, followed by closing words in the discussion.

Part I

Theoretical Part

Structure

The theoretical part of this thesis consists of two chapters: The first chapter explores the current state of research on notifications and their (in many cases negative) implications. The second chapter takes a deeper look into one aspect of notifications in particular that is into vibratory cues. To give an overview, both of these chapters will be summarized in the following paragraphs.

Notifications

In this context, a notification should be understood as a received message on a mobile device, such as a smartphone. A message shall be defined as one of the following: Some kind of text message, voice message (e.g., a call), or some kind of reminder. Furthermore, the kind of message is not of importance. The way of notifying the user, however, is important: This can either be some kind of ringer mode (i.e., an auditory cue) or a vibratory cue.

The following aspects will be of the utmost importance: We will take a look at problems concerning notifications. Since mobile devices are so common these days, more and more studies try to explore the consequences of "being reachable all the time". Various negative consequences have been identified: Ranging from distraction and concentration issues to subjectively less environmental mastery and life satisfaction.

Furthermore, this chapter will deal with the question, whether or not negative effects of notifications can be avoided and whether or not avoidance is practical in daily life. To briefly summarize those two points: Having the mobile device in silent mode, and additionally having it out of sight, helps a lot. Only having the phone in silent mode proved to be much less effective because people tend to check their phones regardless of ringer mode. A cause for that behavior has been identified in the fact that people fear to miss important messages. It has also been documented that users would attend to incoming messages within minutes, regardless of ringer mode.

Another interesting question is whether or not systems are able to predict a better time to start communicating with a person. This is interesting because choosing the right time to contact someone positively affects both the sender and receiver of a notification. Various papers show that this task is very difficult though.

Vibration

Vibratory cues shall be regarded separately as they have various interesting properties:

Vibration is less public in comparison to audible notifications. When auditory cues are just not appropriate in a specific context (e.g., business meeting, theater, church, etc.), vibratory cues can be received possibly without anybody else noticing anything. This makes vibration more versatile in certain situations.

Distinction of different vibration cues is one important point of this section. It shall be explored, how vibration cues or "vibrotactile signals" have to be designed to be distinguishable. Additionally, the perceived urgency of different "on/off" variations of vibrotactile signals shall be regarded.

Suitable body parts for vibration signals are a topic of interest as well. According to studies, different body parts seem to be affected very differently by physical activity in their perception of vibration. These insights are especially interesting for designing wearable vibration devices.

At last, problems and limitations of vibrotactile signals shall be explored. The very nature of a vibration signal demands skin contact in order to be felt which makes it an unreliable form of notification at times. Additionally, physical activity influences the perception of vibration.

CHAPTER 2

Notifications

Notifications are very present in the current time. Smartphones are a major source of notifications and with their ever-rising popularity they make it possible for people to be notified practically everywhere. It is no surprise that a variety of studies have explored how notifications affect people exposed to them.

In this section, exploring potential problems with notifications will be the main focus, with the intent to present solutions for parts of those problems in Section 2.2 *Avoiding Negative Implications of Notifications - Is It Possible?*.

2.1 Effects of Exposure to Notifications

The studies on exposure to notifications can be divided into two categories:

1. **Studies measuring effects of notifications subjectively:** Test persons would be required to answer questions related to notifications throughout such a study. Those reports are commonly done via a daily or weekly questionnaire. Results will always depend on the individual perception of test persons. An example question could be: "On a scale, how interrupted did you feel by a certain notification?"

2. **Studies measuring notification related behavior objectively:** Objective studies would measure various aspects that can be quantified. Those aspects would include time to react to notifications or frequency of phone interaction.

2.1.1 Subjectively Measuring Effects of Notifications

One study, in particular, has been proven to be a valuable source of information on the current status of science in this area: A paper published for CHI 2016 from Kushlev et al. with the title "Silence Your Phones: Smartphone Notifications Increase Inattention and Hyperactivity Symptoms" [1].

This paper deals with the negative effects of receiving notifications. A large number of participants (n=221) were asked to maximize their phone notifications for one week and minimize them (including not having the phone in sight) for another week. Participants had to answer a daily questionnaire [15] about their well being with a larger questionnaire at the end of each week [16]. The participants were asked questions about the following aspects:

- **Interruptions:**
  This was a measurement of how often participants felt interrupted in a given time frame. Interruptions were defined as any time a participant shifted their attention from the current task to their phone because of a notification.
- **Inattention:**
  The measurements for inattention and hyperactivity were based on the book "Diagnostic and statistical manual of mental disorders" by the American Psychiatric Association [17]. Nine questions were formulated based on measurements suggested by [17] regarding inattention. One example: "How often were you easily distracted by external stimuli, like something in your environment or unrelated thoughts?" [16, p. 6]
- **Hyperactivity:**
  The measurements for hyperactivity were based on [17] as well. One example question: "How often did you have difficulty waiting your turn, such as while waiting in line?" [16, p. 7]
- **Productivity:**
  The perceived productivity of participants was measured by asking questions such as: "To what extent, did you feel you got done the things at work or school that were most important to you?" [16, p. 2]
- **Psychological Well-Being:**
  A mix of measures proposed by Ryff et al. [18] and Lee et al. [19] was taken to address issues concerning psychological well-being. The five resulting points were as follows:

  - **Environmental Mastery:**
    To measure the environmental mastery of participants, three statements had to be rated from 1 (strongly disagree) to 7 (strongly agree). One such statement was: "I was quite good at managing the many responsibilities of my daily life" [16, p. 2].

- **Social Connectedness:**
  This aspect measured, how connected participants felt to others. Participants were asked about their agreements with five statements such as: "I didn't feel related to most people" [16, p. 3].
- **Perceived Choice:**
  Five items about perceived choice in life were based on the Perceived Choice Scale by Sheldon et al. [20, 21]. Participants had to choose in five instances which of two opposing sentences felt more accurate. One such pair of sentences was as follows: "A: I felt like I always chose the things I did. B: I sometimes felt that I was not really choosing the things I did." [16, p. 5]
- **Meaning in Life:**
  In an attempt to measure meaning in life in such an evaluation time frame, Kushlev et al. took five points of the "The meaning in life questionnaire" [22]. Example question: "I had a good sense of what makes my life meaningful" [16, p. 4].
- **Life satisfaction:**
  The question for life satisfaction was another one where little effect was expected within the test period. The example question in this case was: "I had discovered a satisfying life purpose" [16, p. 4].

To achieve meaningful results, Kushlev et al. asked the participants to fill out a baseline questionnaire [23]. Those results established a baseline measure before the start of the experiment. The baseline results can be seen in Figure 2.1.

	Interruptions	Inattention	Hyperactivity	Productivity	Environmental Mastery	Social Connectedness	Perceived Choice	Meaning in Life	Life Satisfaction
Interruptions	–								
Inattention	.31***	–							
Hyperactivity	.30***	.41***	–						
Productivity	–.14*	–.41***	–.09	–					
Environmental Mastery	–.18**	–.52***	–.27***	.34***	–				
Social Connectedness	.01	–.26***	–.27***	0.13*	.29***	–			
Perceived Choice	–.09	–.36***	–.13†	.25***	.35***	.24***	–		
Meaning in Life	–.11†	–.28***	–.11	.36***	.49***	.35***	.38***	–	
Life Satisfaction	–.05	–.41***	–.15*	.42***	.64***	.46***	.39***	.50***	–

Figure 2.1: Table of correlations between baseline measures. *** $p < .001$; ** $p < .01$; * $p < .05$; † $p < .10$ [1].

Interestingly enough, there is a strong correlation between inattention and (to a lesser degree) hyperactivity and various negative effects, such as reduced productivity and generally reduced psychological well-being [1, p. 1014-1016]. Figure 2.1 shows the effect of the bold keywords on top (columns) on the keywords on the left side (rows). Kushlev et al. explained that inattention has the strongest negative effect on productivity, environmental mastery, and perceived choice in life. Therefore they tried to figure out the direction of correlation between interruption and inattention. Considering that (based on the baseline results) inattention could mean being more easily interrupted by external triggers. They proceeded to answer this question of causality with their specific experimental lineup of having the participants minimize and maximize their phone notification for one week each, in an attempt to control the interruption-factor.

It could be established that the "Do-Not-Interrupt condition" did in fact cause participants to feel less interrupted compared to the "Interrupt condition" as well as the baseline measurements [1, p. 1016]. Interestingly enough, participants did not feel more interrupted in the interrupt condition than they did at baseline.

It turned out that higher levels of inattention were caused by maximizing interruptions, whereas reducing interruptions caused lower levels of inattention. Both of these effects "were of medium size according to established statistical guidelines in the behavioral sciences" [2], however. No significant changes in productivity or psychological well-being could be recorded during the time of the experiment. However, the authors suggested that the time period of one week could be too short to produce significant results for those factors.

Figure 2.2 proceeds to show the indirect effects of interruption manipulation. It shows that "to the extent that people experienced greater inattention in the Interrupt (vs. Do-Not-Interrupt) condition, they felt less productive and less socially connected, reported less mastery over their environment, and lower meaning in life, and perceived less choice over their actions" [1, p. 1016]. This means that inattention is the cause for the aforementioned negative effects. The level of interruption has a direct effect on the level of inattention, therefore indirectly increasing those negative effects.

Kushlev et al. concluded that "interruptions might cause symptoms of ADHD in the general population" [1, p. 1017]. Furthermore, those negative effects could be reduced by "making simple modifications to the notification settings of [..] phones" [1, p. 1017]. However, it should be mentioned that the study Kushlev et al. explicitly stated that their "findings do not in any way suggest that smartphone notifications can cause ADHD" [1, p. 1018].

Those findings lay out an interesting basis for future research and it can be expected that the provided angles will be explored further.

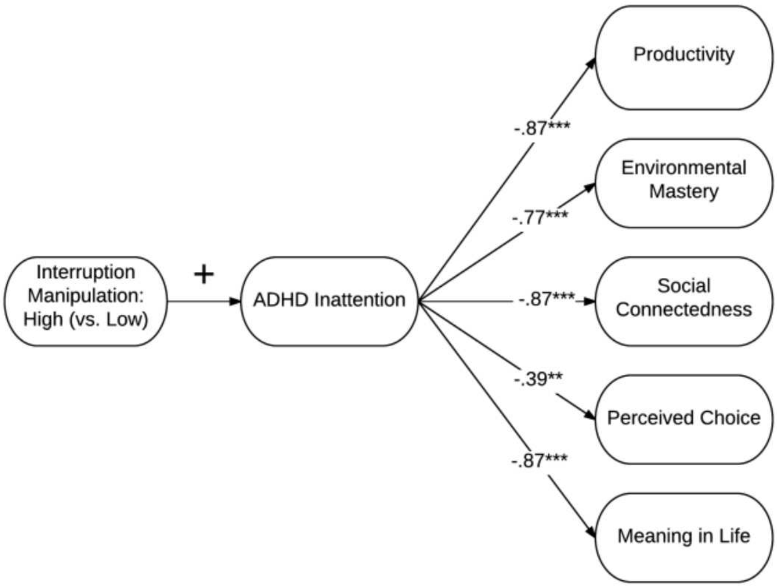
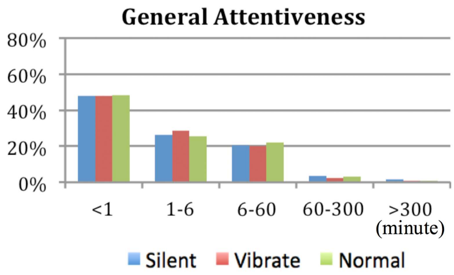


Figure 2.2: Indirect effects of manipulating smartphone interruptions on psychological well-being via inattention symptoms. Numbers are unstandardized regression coefficients [1, p. 1015].

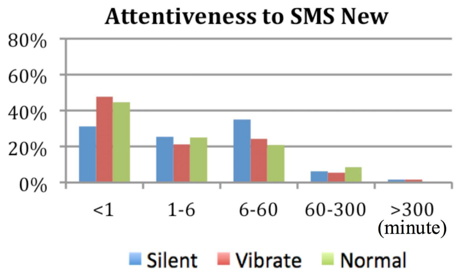
2.1.2 Objectively Measuring Notification Related Behavior

Chang et al. [2] took objective measures to get insights into notification usage, usage of ringer modes, and reaction to notifications. For their study, they developed an application that would log notification related events on Android phones. The application would log incoming and outgoing notifications and calls, as well as ringer mode changes. Additionally, context information would be taken via the Google activity recognition service Application Programming Interface (API) [24] which can distinguish between five different types of activities: still, tilting, driving, on a bike, and walking. 28 participants (16 male, 12 female) successfully finished a two-week-study. To get qualitative feedback, events such as "missed or declined phone calls, periods with unread notifications for over an hour, and ringer mode changes" were recorded. Three of those events within the last 24 hours were randomly selected each day and the participants were prompted with questions about those events. For the data analysis, SMS messages were taken into consideration to achieve a combination of qualitative and quantitative results. The three ringer modes silent, vibrate, and normal were observed for their usage in detail.

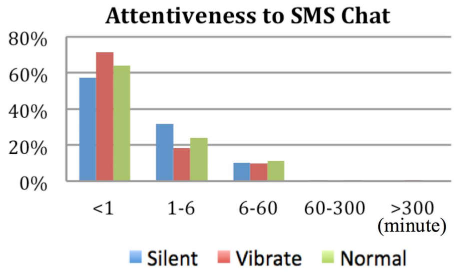
According to Chang et al. [2, p. 10], the reasons for using silent mode (i.e., audible signals and vibratory signals disabled) as stated by the test persons were as follows: "going to bed", "going to a meeting", "being at work", or "being in situations where the phone sound was interrupting and disrupting". It has to be pointed out that silent mode still has visual indications of incoming messages, such as a flashing display or pulsating Light-Emitting Diodes (LEDs).



(a) Intervals between attending actions for general usage across ringer modes.



(b) Intervals between receiving SMS new messages and the first attending action.



(c) Intervals between receiving SMS chat messages and the first attending action.

Figure 2.3: Intervals between receiving notifications and attending them [2, p. 11] (reproduced for visual consistency).

Vibrate mode (i.e., audible signals disabled, vibratory signals enabled) was used for similar reasons as "silent mode". Participants thought that vibrate mode was sufficiently silent and liked that they were still able to notice notifications easily.

Normal mode (i.e., audible signals enabled) was generally switched to for the following reasons: "enhancing awareness of notifications after leaving work", "getting up from bed", or "leaving environments where phone sounds were considered disruptive". For each of those modes, the response time was measured.

Figure 2.3 highlights the attentiveness of participants to incoming notifications by measuring the time between receiving a notification and the first attending action. Figure 2.3a shows that the general attentiveness to the phone across different ringer mode is very similar. The majority of participants reacted within 6 minutes, regardless of ringer mode.

The study [2, p. 9] further focused on the attentiveness of SMS, where they distinguished two different types of SMS communication: new SMS messages (referred to as "SMS New") and SMS conversations (referred to as "SMS Chat"). According to Battestini et al., the "average time to reply to a text message received or receive a reply to a text message sent was 6:04 minutes" [25, p. 232]. Based on that finding, Chang et al. define "SMS Chat" to be a message with "at least one message exchanged within 6 minutes before the current message" [2, p. 9]. All other messages are defined to be "SMS New" messages. It has to be noted though that Battestini et al. had a different definition of a "text message conversation", as they grouped messages as a conversation when there was at least one incoming and one outgoing message within a period of 20 minutes.

As seen in Figure 2.3b, the attentiveness within 1 minute was much lower for Silent mode (31.4%) in comparison to Vibrate (47.5%) and Normal (44.8%). The values for 1-6 minutes, however, are very close throughout the different ringer modes, with 25.6%, 21.2% and 25% respectively. Those numbers conclude that 57% of SMS New messages were answered within 6 minutes in Silent mode, 68.7% in Vibrate mode and 69.8% in Normal mode. This highlights, how similar Vibrate and Normal mode are in respect to attentiveness within the conversation parameters as defined by Battestini et al [25, p. 233-234]. By definition, this should mean that SMS Chat messages occur less often for participants who have their phone in Silent mode, in contrast to people who have their phone in either Vibrate or Normal mode. Since raw data is not available, this can only be speculation.

Figure 2.3c shows the results for SMS Chat messages and as expected the attentiveness is higher for all ringer modes than it is for SMS New messages [2, p. 11]. The attentiveness within 1 minute for Silent mode almost doubled to 57.3%, for Vibrate mode it went up to 71.5%, and for Normal mode the attentiveness within 1 minute reached 64%. The values for 1-6 minutes were more in line with the values for the corresponding time for SMS New messages (Silent: 31.8%, Vibrate: 18.2% and Normal: 24.2%). This means that 89.1% attended SMS Chat message in Silent mode within 6 minutes, 89.7% did the same with Vibrate mode and 88.2% with Normal mode. Those numbers are remarkably close to each other.

It can be concluded that the ringer mode does have an impact on the attentiveness of users, especially on SMS new messages. Without notification signals, the attentiveness to incoming messages decreases. However, it has to be pointed out that even in Silent mode more than half of the time notifications were seen within 6 minutes.

2.2 Avoiding Negative Implications of Notifications - Is It Possible?

Recognizing negative implications of notifications is no new topic in research, neither are attempts to reduce those negative implications. In that regard, Hansson et al. had an interesting approach in the year 2000 in their paper "The Reminder Bracelet: Subtle Notification Cues for Mobile Devices" [3, p. 323-324].

They recognized that devices such as mobile phones, pagers, and PDAs could lead to attention overload [3, p. 323]. One of the main problems concerning notification devices has been described to be the fact that not only the owner of a device may get distracted by notification, but also people nearby. In an attempt to lessen distractions by attention-demanding notification sounds, Hansson et al. developed the "Reminder Bracelet". It has been developed in an effort to make a public and subtle notification device.

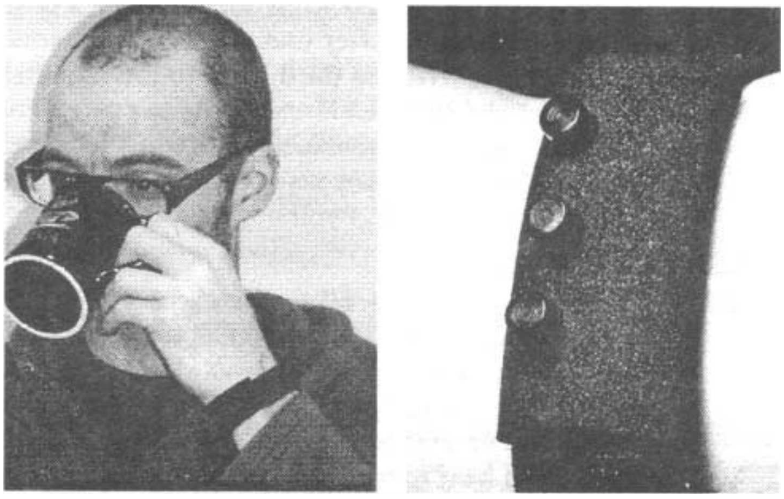


Figure 2.4: A user wearing the Reminder Bracelet [3, p. 323].

The bracelet has a publicly visible notification cue, making it easier for bystanders to understand when a notification cue happens. It is a bracelet made out of black textile material with Velcro on the inside ("much like a sports watch wristband" [3, p. 324]) and uses a thin cable to connect to a PDA. It uses three LEDs to notify a user about upcoming events in their calendar. Figure 2.4 shows the design of the Reminder Bracelet. The bracelet makes sure that the user does not miss events by regularly checking the calendar of the PDA. The LEDs start to pulsate before an event one at a time until all three of them twinkle[1].

Hansson et al. chose four test persons to test the (prototype) bracelet for two days. During that time, those test persons did not always realize when they were notified however because they "had difficulties perceiving the light transmitted from the LEDs" [3, p. 324]. Because of those issues, the test persons described that they could not fully trust the bracelet, but they "all agreed that it would be a useful tool if the issue of trust could be resolved" [3, p. 324].

Hansson et al. proceeded to address those problems by replacing the LEDs with higher intensity LEDs. After those modifications, two of the original test persons were chosen to repeat the test for one day. With those improvements, the test users were able to be notified of each event and the trust in the system improved.

According to the test users, "the Reminder Bracelet conveyed the notifications in a manner which they perceived to be subtle and non-intrusive and they were both of the opinions that they would prefer to be notified by the prototype rather than by a typical alert sound" [3, p. 324].

Hansson et al. could imagine seeing "emerging technologies like Bluetooth" [3, p. 324]

[1] Note: the frequency and light intensity have not been specified further.

replace the cable of future bracelets and make the bracelet wireless.

One year later, Hansson et al. published a follow-up paper with the title “Subtle and Public Notification Cues for Mobile Devices” [12].

In this paper they point out the negative implications of auditory cues as well as tactile cues. According to Hansson et al., the problem with auditory cues lies in the fact that they can be “attention demanding, distinct and intrusive and therefore be perceived as inappropriate in many social situations” [12, p. 243].

While those problems could be avoided by silencing the corresponding mobile device that would not always be a satisfactory solution because the information might be important for the user. This problem defined as “communication deficiency” by Ljungberg et al. and describes “situations where people are subjected to communication which they are interested in, but where the mode of communication is undesired” [26].

Hansson et al. argue that people in hearing distance of auditory cues can be “overwhelmed and interrupted” by those cues and proceed to introduce terms to categorize different types of notification cues [12].

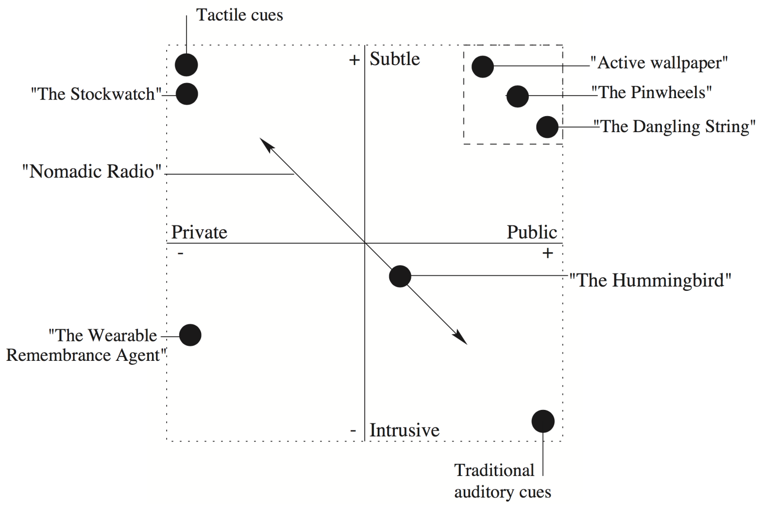


Figure 2.5: A model for visualizing subtleness vs. publicity with regard to notification cues [12, p. 244].

Figure 2.5 shows a chart with two axes, with pairwise opposites.

On the x-axis, the opposing characteristics “private” and “public” are listed. Where a “private” notification cue would only be recognizable for the receiving person, a “public” notification cue would be recognizable for people around the intended recipient. Examples for the former would be vibrotactile signals, whereas the auditory cues would rather be considered “public.”

The y-axis is a little bit more tricky, as it contains the opposing characteristics “subtle” and “intrusive.” A “subtle” notification cue is one that “conveys information in a non-intrusive and gentle manner” [12, p. 244]. “Intrusive” notification cues would demand immediate attention of the receiver and might also cause attention of people nearby.

Hansson et al. associate attention overload with intrusive notification cues, such as “loud auditory cues or flashing bright lights” [12, p. 242]. They also argue that private notification cues have an inherent problem of only being recognizable by the receiver which can lead to unintuitive situations for other people nearby.

In one example, they described a situation where a group of people engaged in a conversation was interrupted by an incoming call. It would be perfectly understandable for everyone if the conversation suddenly stopped due to a public notification cue, such as an auditory cue. However, a vibratory cue would only be perceived by the receiver and therefore could lead to situations that are not intuitively understandable for bystanders.

For those reasons, Hansson et al. argue that public notifications are preferable. Additionally, subtle notification cues should be considered to counter “attention overload”. Hansson et al. conclude that “it is desirable to design notification cues which combine the qualities of being subtle and public” [12, p. 243].

Further research concerning public and subtle notification devices

William et al. made an effort to develop a subtle and public notification device in their paper “Exploring wearable ambient displays for social awareness” [13].

In this paper William et al. introduce their “wearable ambient display” named “Damage”. Damage is a follow-up project to “Slam”, which is a group chat application for phones, developed by the same team. It was stated that one of the most compelling reasons for people to buy a cell phone was to “coordinate a family’s complex schedule” [13, p. 1530].

The pairwise communication capabilities (i.e., SMS) were addressed by Slam by introducing “group communication”, a form of one-to-many and many-to-many communication. Messages were sent to an entire group, including the capability to send photos. The system was well received in a 10-day-long study and the test persons felt “significantly more connected to their social group” [13, p. 1530]. An average of 3.98 messages were sent per day, including simple “good night” messages. Some people regarded the constant vibration “as a nuisance” [13, p. 1531] however.

Damage, “named so because it provides tangible evidence for slamming” [13, p. 1531], addressed that issue. It is a “semi-public piece of jewelry” [13, p. 1531], with 6 attached studs which are described to be “similar to a studded bracelet” [13, p. 1531] (see Figure 2.6). Each stud contains four LEDs in red, blue, green, and white. Five of those studs represent different persons, whereas the sixth stud represents a group message. The meaning of each color is determined by mutual agreement of the corresponding group. Different colored messages can be sent directly from the bracelet by opening and closing three metal snaps.

Figure 2.6: Damage design sketch [13, p. 1532].

Two focus groups were conducted (ages 20-30 and ages 16-19) to determine the design for such a device [13, p. 1532-1533]. Interestingly enough, "**designs involving bracelets and watches were [most] popular** [..]" [13, p. 1532]. "Necklace displays" have been suggested by a few participants as well, even though they have the disadvantage of being more visible. William et al. described that the younger set of test persons were generally more positive towards the developed physical prototype [13, p. 1532]. Almost all wanted greater flexibility like more studs or the ability to only track a significant other. The younger ones had concerns that they would get in trouble in class. They wanted something more subtle, like a watch that would have given them a legitimate reason to look at their wrist.

In their design consideration for a peripheral, non-distracting ambient display Williams et al. reference the Hansson papers [3, 12].

CHAPTER 3

Vibration

For this thesis, when writing about "vibrotactile signals", the American English definition of "vibrotactile" of the "Oxford Dictionaries" will be used: "Vibrotactile: Relating to or involving the perception of vibration through touch" [27].

With this definition in mind, a vibrotactile signal shall be understood as a "vibration message" that is perceived as vibration through touch.

The determining factors for differentiating different vibrotactile signals will be explored. Also, an important aspect will be the perceived urgency of said vibrotactile signal. It will be determined, how much information can be encoded into a vibration signal. Including different, distinguishable meanings and distinction between a set number of possible senders.

Background

The human skin has good potential as a communication medium [28, p. 15]. A touch on the hand or other parts of the body is a very rich experience. With about $2m^2$ in an average male [29], it is the largest organ in the body.

There are two categories of touch that can be sensed: kinaesthetic[1] and cutaneous[2]. Where the former describes the perception of forces through muscles and joints, the latter describes the perception through the skin, such as vibration, temperature, or pain.

It has been concluded that especially the cutaneous sense is very effective for communication. For both categories, there exist devices that give respective feedback to users.

[1] "Kinaesthetic" is often used as catch-all term to describe the information arising from forces and positions sensed by the muscles and joints. Force-feedback haptic devices (such as the PHANToM from SensAble) are used to present information to the kinaesthetic sense [28].

[2] Cutaneous perception refers to the mechanoreceptors contained within the skin, and includes the sensations of vibration, temperature, pain, and indentation [28].

Kinaesthetic sense: For the kinaesthetic sense, such devices would be called "haptic devices" [30]. There are devices such as the PHANTOM OMNI® HAPTIC DEVICE [31] with haptic feedback. The handling of that device is similar to handling a pencil and a user is able to "touch" virtual objects with it via force feedback. Such devices are one-point-of-contact haptic displays, meaning that the user can only feel one single point of an object at a time. Because of that, users have to memorize the structure they are feeling which makes it difficult to recognize objects. Jansson and Larsson [30] concluded that the usefulness of such haptic devices decreases when the complexity of virtual objects increases.

For such complex objects, touch is much more effective and should, therefore, be included in haptic displays [28, p. 15].

Cutaneous sense: Devices that use the touch sense, or cutaneous sense, are called "tactile devices" [32, p. 84]. There have been different studies about the cutaneous sense being very effective for transmitting information. However, the sense of touch is underutilized in Human-Computer Interaction (HCI) compared to vision and audition.

Brewster and Brown made an effort to analyze ways to use the cutaneous sense for a "vibrotactile display device" [28, p. 16]. They defined "tactons[3]" as a counterpart to "icons" or "earcons[4]": "Tactons, or tactile icons, are structured, abstract messages that can be used to communicate messages non-visually" [28, p. 15]. Icons are a visual representation of potentially complex information. Earcons are sounds that convey information. Both of them have in common that simple information can be conveyed in a very fast and effective way. In this regard, icons would be compared to text and earcons would be compared to speech. A simple message can be expressed by an icon, where a textual description would most likely be more verbose, the same holds true for earcons. Icons are good for displaying spacial information and earcons are good for displaying temporal information. Tactons can be used to display both spatial and temporal information. These three display methods all have their strengths and weaknesses. Visual displays with icons allow very fast recognition of messages but they require visual attention. Earcons do not require visual attention but they might not be very practical in very noisy or very silent environments. Tactons are very promising to solve those two issues.

[3]Tactons, or tactile icons, are structured, abstract messages that can be used to communicate messages non-visually [28].

[4]"Sounds can be grouped or structured along principles similar to those of icons. We call such structured sounds earcons which are defined as nonverbal audio messages used in the user-computer interface to provide information to the user about some computer object, operation, or interaction. Examples of computer objects are files, menus, and prompts. Editing, compiling, and executing are examples of operations. An example of an interaction between an object and an operation is editing a file. Earcons, then, are the aural counterparts of icons" [33].

3.1 Physical Perception of Vibratory Signals

Vibration is perceived differently by different parts of the body. Machida et al. had valuable insights into this particular topic, when they searched for "Suitable Body Parts for Vibration Feedback in Walking Navigation Systems" [14].

In their study, they had 10 test persons (7 male and 3 female) between the ages of 20 to 26 wear vibration devices on 8 different parts of their body. The vibration devices were designed in a way that participants would feel the vibration through clothing. That choice was made "based on [their] preliminary observation that users generally regard direct touch of vibration sensors to be uncomfortable" [14, p. 33]. All vibration devices had the same vibration intensity, as they were all using the same type of LilyPad vibration motors (note: technical details and images within the paper make it apparent that *LilyPad Vibe Boards* [34] were used).

Machida et al. performed their experiment [14, p. 33, 34] in three conditions and eight vibration positions:

Conditions

- **Standing:** Participants would receive 3 vibration signals of 1000 ms with a time gap of 2.5 seconds while standing.
- **Walking:** Participants would receive 3 vibration signals of 1500 ms with a time gap of 2.5 seconds while walking with 4.5 km/h on a walking machine.
- **Running:** Participants would receive 3 vibration signals of 1500 ms with a time gap of 2.5 seconds while running with 16.2 km/h on a walking machine.

Vibration positions (see [14, p. 33]):

- **Ears:** Attached to ear-rings.
- **Neck:** Attached to necklace.
- **Wrist:** Embedded in watch.
- **Hand:** Attached to glove.
- **Chest:** Attached to shirt.
- **Waist:** Attached to belt.
- **Ankle:** Attached to sock.
- **Foot:** Attached to shoe at front foot position.

Each vibration position was remotely triggered for vibration and participants had to give feedback on the "ease of perception of the vibration" [14, p. 34].

Figure 3.1 shows the results for each position and condition. According to the study, the ears show the best results in all categories, followed by hands, feet, wrists, and neck.

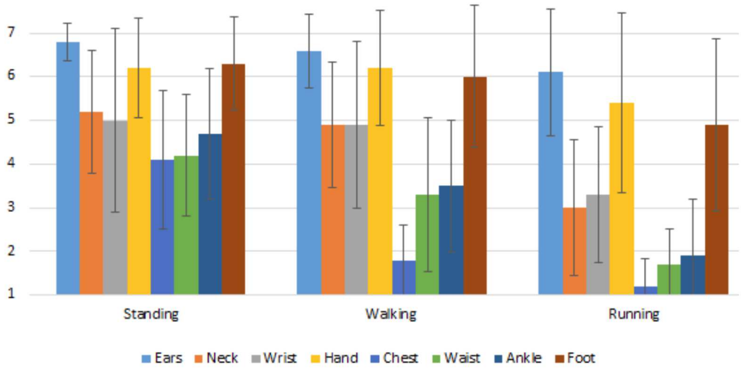


Figure 3.1: Perception rating for vibration positions and activity levels [14, p. 35].

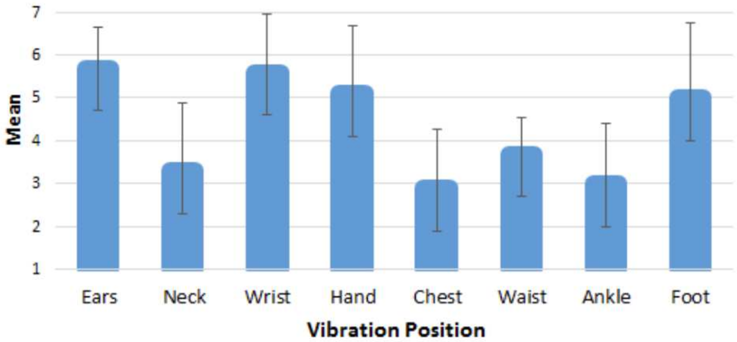


Figure 3.2: Preference for vibration positions [14, p. 35].

In the 7-point Likert scale used (with 7 being the best result), only ears stay above an average perception level of 6 for all conditions. Most notably is the drop of the average perception level from the condition "Walking" to "Running".

Machida et al. proceeded to ask the test person about their preferred vibration position [14, p. 35]. As seen in Figure 3.2, there are four vibration positions with an average value between 5 and 6, with the rest being between 3 and 4. The preferred vibration locations are as follows: ears, wrists, hands, and feet.

The study shows that wrists are a very suitable location for receiving vibration signals which is an interesting insight for various vibration devices, such as smartwatches or fitness bracelets. Those devices are very suitable for having vibration capabilities.

3.2 Distinguishability of Vibrotactile Signals

It has been shown that several different messages can be distinguished by using different vibration patterns [11, 35].

Designing vibrotactile coding schemes and rendering vibrotactile patterns for the blind show the potential of vibration patterns [36, 28]. Use cases such as navigation systems via "vibrotactile feedback" have been evaluated [37, 38]. Studies also suggest that vibration patterns can form "non-annoying, light-weight information displays" [39, p. 1557] which makes them very interesting for developing discrete notification systems.

As outlined in 2.2 *Avoiding Negative Implications of Notifications - Is It Possible?*, Hansson et al. [12] use the term "subtlety" to describe non-intrusive notification cues. Vibration has been rated as "very subtle" [12, p. 241] in this context. In contrast to intrusive notifications, non-intrusive notifications do not contribute to information overload.

To be able to understand how much information may be put into a vibrotactile signal, it is important to first understand which distinguishable factors may be used for a vibration message.

3.2.1 Perceived Urgency of Vibrotactile Signals

Saket et al. had interesting insights into that topic in their paper "Designing an Effective Vibration-based Notification Interface for Mobile Phones" [11].

They made an empirical study on the factors that determine as how urgent a vibration signal is perceived. Additionally, Saket et al. wanted to determine how many vibration patterns could reliably be distinguished and associated at the same level of urgency by different users.

In a pilot study, they determined that the appropriate lengths of short and long vibration signal, with short signals being 200ms long and long signals 600ms. It showed that patterns composed of only short and long vibration lengths were much easier to distinguish than patterns with more intermediate lengths.

Saket et al. proceeded to design 10 vibration patterns, composed of only the following sequences: short on, short off, long on, long off [11, p. 1500]. All vibration patterns either had one or two on/off sequences and were repeated for 4.5 seconds, as shown in Figure 3.3.

Their user test included 16 participants (6 female, 10 male) with ages ranging from 19 to 25. Those test users were asked to rate the perceived urgency of all vibration signals in a pairwise comparison.

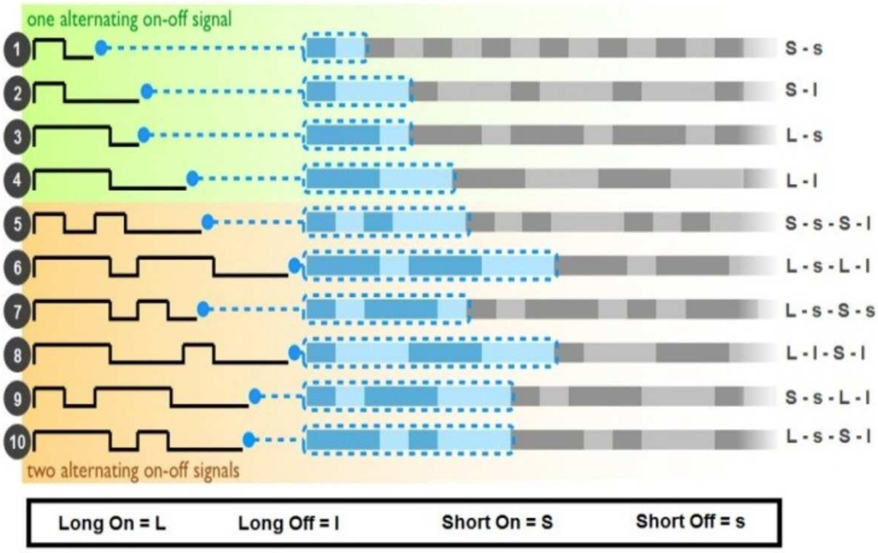


Figure 3.3: All possible permutations of short (200 ms) and long (600 ms) on-off signals. Each pattern is repeated until a total duration of 4,500 ms [11, p. 1500].

There were four possible answers for the participants:

1: the first pattern is more urgent
2: the second pattern is more urgent
1 ≅ 2: the first and second patterns are comparable
Repeat: perform the comparison again [11, p. 1501]

Using clustering algorithms, Saket et al. were able to bring all 10 vibration patterns into a distinct order. Figure 3.4 shows the vibration patterns ordered by priority from left to right (most urgent to least urgent).

Saket et al. determined three major factors that contribute to the perceived urgency of a vibrotactile signal: "gap length, number of gaps, and vibration length" [11, p. 1499].

- **Gap length:** This was the most significant factor. A short gap (200ms) increased the perceived urgency.
- **Number of gaps:** A pattern with one gap was perceived as more urgent.
- **Vibration length:** Vibration patterns with shorter vibrations were perceived as more urgent.

Recognizing urgency levels

In a second experiment, Saket et al. tested how many urgency levels could be recognized reliably [11, p. 1503]. With 12 new test users (6 female, 6 male) with ages ranging form

Vibration Patterns

	1	3	6	9	7	4	5	8	10	2
One Short Off	X	X								
One Long Off						X				X
Two Short Off					X					
Two Long Off								X		
Two Mixed Off			X	X			X		X	
One Short On	X									X
One Long On		X				X				
Two Short On							X			
Two Long On			X							
Two Mixed On				X	X			X	X	

Figure 3.4: From most urgent (left) to least urgent (right): 10 signal characteristics of vibration patterns ordered by perceived urgency [11, p. 1502].

19 to 25, Saket et al. tested whether four, five, or six different urgency levels could be distinguished reliably. The participants were told how many urgency levels there would be for each test beforehand. Then they rated each incoming signal by holding up a card, indicating which urgency levels they had perceived.

Results showed that test persons could reliably distinguish four to five urgency levels with an accuracy of 95.8% and 81.7% respectively [11, p. 1503]. Six and more urgency levels were recognized correctly only 57% of the time.

3.3 State of the Art of Existing Solutions

Currently there exists no vibrating bracelet that acts as a notification device for important notification. Creating smart bracelets for different use-cases is becoming popular however. With smaller and more powerful hardware parts, there are a several interesting developments.

3.3.1 Vibrating Bracelets

1. **MEMI [10, 9]**

   This smart bracelet got funded through Kickstarter at the end of November 2013 and is currently in the final stages of development. It informs the wearer via vibration when there is a call or message from a person that is on a list of persons who can get through to the bracelet.

   In contrast to MEMI, Discrete notifications via vibrotactile signals (Dinovis) (see 5.1 *Development and Implementation*) will have an open API which will be controllable not only from an iOS application but also any future application that uses the open API. The primary focus of MEMI is the notification of calls and messages by predefined persons, whereas the primary focus of this development is the possibility to send and receive a number of notifications that are distinguishable via different vibration patterns, without having to look at a display (e.g., cell phone).

2. **TapTap [8, 7]**

   TapTap is a bracelet that transfers touch between two people. Whenever one person touches the surface of their bracelet, the other bracelet begins to vibrate. The developers explained that a "secret language" could be developed between two participants, where only they would know the meaning of certain tap combinations.

   One fundamental difference between TapTap and Dinovis is that TapTap is only designed to connect two persons with each other, so it does not try to solve the complex issue of distinguishing between different senders (see Point 1 in Section 1.2.1 *Research Questions*).

   Having a different use-case as a goal, TapTap is still interesting because it has been announced to have an open SDK. As it is still in development, details about the SDK have not been released yet.

3. **Jawbone UP24 [4, 5]**

   "UP helps you understand how you sleep, move and eat so you can make smarter choices" [4]. Jawbone UP24 is a vibrating bracelet that includes functions such as vibration alarms to wake up the wearer at the perfect point of his or her sleep cycle. UP24 connects via Bluetooth 4.0 [40] to a corresponding iOS or Android application which makes the architecture similar to Dinovis.

Part II

Practical Part

CHAPTER 4

Methodology and Approach

This chapter describes the methodological background of this thesis. The methodologies used will be explained theoretically first. Afterwards, it will be explained how those methodologies are used in the context of thesis.

Qualitative and quantitative research will be explained and compared to each other. The user-centered approach will be described and different kinds of prototyping will be discussed.

4.1 Qualitative and Quantitative Research

Qualitative and quantitative research represent two opposites [41, p. 32-33]. Where qualitative research uses open questions, quantitative research focuses on numbers. Typical examples would be qualitative case studies or quantitative experiments.

Choosing a qualitative or quantitative approach for data gathering has a lot to do with the intent of the thesis. One major difference between the two approaches is the way how results are achieved.

Quantitative research: As the name itself suggests, quantitative research measures in numbers. The Oxford dictionary describes "quantitative" as follows: "Relating to, measuring, or measured by the quantity of something rather than its quality" [42].

A common use case for using quantitative research would be to test or validate existing research [43, 44]. Typically, quantitative research data would be collected using questionnaires that can be completed by test persons without the need for a supervisor. For one, this means that questions have to be self-explanatory. Questions have to be precise and understandable. Secondly, questions and their respective answers have to be formulated in advance. Meaning that even though test persons might want to answer certain questions differently or would like to give additional input, they cannot do that if the questionnaire was not designed for that scenario specifically. This reason makes quantitative research excellent for fields, where relevant variables are known in advance. Quantitative research is very well fit for getting an overview of a specific field or topic.

Qualitative research: Qualitative research, on the other hand, is about in-depth analysis. The respective definition of “qualitative” in the Oxford Dictionary is as follows: “Relating to, measuring, or measured by the quality of something rather than its quantity” [45].

Commonly, qualitative research would be used to prove new theories or in fields that are not well known [43, 44]. Gathering data for quantitative research typically requires large numbers of test persons. Contrary to that, qualitative research relies more on selecting specific, representative test persons. Those test persons are given much more room in answering relevant questions. An open interview would be a typical example for data gathering in qualitative research. The outcome of such an open interview is much less predictable than it would be in quantitative research. When analyzing qualitative data, induction is used to generalize individual results.

4.2 User-Centered Approach

User-Centered Design (UCD) is a term that is used to describe a design paradigm that includes the end-user into the design process. The goal of UCD is to design intuitive and user friendly products.

Even though there are different ways to involve users in UCD, the core concept always remains user involvement [46, p. 1]. Users are typically asked for feedback during requirements gathering and usability testing.

In the late 1980s, Donald A. Norman defined four basic principles about UCD [47, p. 188]:

1. “Make it easy to determine what actions are possible at any moment.”
2. “Make things visible, including the conceptual model of the system, the alternative actions, and the results of actions.”
3. “Make it easy to evaluate the current state of the system.”
4. “Follow natural mappings between intentions and the required actions; between actions and the resulting effect; and between the information that is visible and the interpretation of the system state.”

With those design principles, Norman places the user in the center of the design process [46, p. 1-3]. Users should be able to use a system with minimal learning effort. According to

Norman, long user manuals are not user friendly. A much better approach would be to have a very brief introduction to a system and letting the user draw on knowledge from real-world experience.

4.3 Prototyping

Prototyping has been recognized as an effective method in development processes [48, p. 77-78]. Especially for developing User Interfaces (UIs). Prototypes can generally be divided into two groups: low-fidelity and high-fidelity prototypes. Prototypes do not always need to be complete to be effective.

Low-fidelity prototypes: Low-fidelity prototypes generally have limited function and interaction capabilities [48, p. 79-80]. They are functionally not complete but offer a good impression of how the final product will be used. The intent of a low-fidelity prototype is to rapidly develop a prototype that is able to solve 80% of major interface problems. Low-fidelity prototypes are often operated by someone in a scripted way, to simulate functionality that is not yet implemented. In such cases a supervisor, who knows how the application is supposed to behave, is reacting to user input and triggers missing functionality. Low-fidelity prototypes can be realized on paper to evaluate how well a certain design meets the requirements early on. Feedback is used to either build another iteration of a low-fidelity prototype, or as input for creating a higher fidelity prototype. Those prototypes focus on user interface design and improvement of the same.

Disadvantages: Low-fidelity prototypes provide very little error checking which can result in important things being overlooked. Since low-fidelity prototypes are not fully functional, it is much more difficult to identify design inconsistencies and shortcomings [48, p. 80-81]. As pointed out in [49], low-fidelity prototypes make it much harder for test persons to notice design flaws in comparison to high-fidelity prototypes. In the experiment in [49], test persons were asked to identify problems for both a low-fidelity and a high-fidelity prototype of the same application. Both prototypes intentionally had the same design flaws. With high-fidelity prototypes however, test persons were able to notice significantly more problems [49, p. 318-319].

High-fidelity prototypes: High-fidelity prototypes are fully functional and interactive [48, p. 81-82]. Such prototypes represent the final product very accurately. They can be made so realistic that they are hard to distinguish from the finished product. Because those prototypes are very accurate, they are taking considerably longer to build. High-fidelity prototypes respond like the finished product. With such a prototype, there is no need for a supervisor to simulate behavior anymore. The prototype works autonomously, including details such as proper error messages. Since a high-fidelity prototype will behave so similar to the finished product, test persons are better able to give precise feedback and recommendations for improvement. A high-fidelity prototype also helps developers to get a better feel for their product and therefore identify potential problems.

Disadvantages: High-fidelity prototypes require much more time, money, and effort to develop [48, p. 82-83]. Since the prototype represents the final product so accurately, their development becomes a serious effort. While it is enough to have good designers for user interface development of low-fidelity prototypes, high-fidelity prototypes require the work of both good designers and developers. Additionally, high-fidelity prototypes might seem finished to a customer, long before they really are. It might be difficult to explain to customers that there is still a lot of development and testing left to be done. Furthermore, the final product might still be different from a high-fidelity prototype. For instance, features presented in the prototype might not make it into the final product for various reasons. High-fidelity prototypes are also not very practical for testing a lot of different design approaches. With all the little details needed to develop a high-fidelity prototype, it is simply too much effort to use them for fundamental design evaluations. Low-fidelity prototypes fit much more in those cases.

Mixing high-fidelity and low-fidelity: There is a middle ground between high-fidelity and low-fidelity however, where certain aspects are very detailed, while others are only rudimentary [48, p. 78, 84-85]. A "vertical prototype" is a very detailed high-fidelity prototype with only a subset of functionality available. There is also a "horizontal prototype" which contains high-level functionality, while omitting low-level details. Those two variants are faster to create than high-fidelity prototypes, while still providing selected functionality.

4.4 Concrete Implementation of Methodologies

The implementation of methodologies has been adapted to fit the requirements of this thesis. In the following enumeration, the general workflow of the thesis will be described, as well as the concrete implementation of methodologies. Whenever there are deviations from one of the described methodologies, those deviations will be explained in detail.

1. **Literature review and evaluation**

   First, there will be a detailed review of the literature available concerning notifications in general and vibrotactile signals specifically. The goal of this step is to gain insights into the current state of research concerning those topics. Also, state of the art technology shall be evaluated. That part also includes an evaluation of possible hardware parts for a vibrating bracelet and the creation of a design which contains all the necessary hardware.

   The literature review concerning notifications in general will be described in Chapter 2 *Notifications*, while vibration related notifications will be analyzed in Chapter 3 *Vibration*.

The evaluation of hardware parts will be disclosed in Section 5.2 *Vibrating Bracelet*.

2. **Building a prototype**

   This step is about developing the relevant software and hardware parts, getting all parts to communicate with each other, and implementing core functionality. That means that it should be possible to send an alarm from the iOS application to the bracelet and the bracelet should vibrate, including all steps in between. See Figure 5.1 for details.

   The methodology of "prototyping" will be used to implement the required functionality. A mix of high-fidelity and low-fidelity prototype will be used. To best evaluate the prototype, it is necessary to build a bracelet that can be worn by test persons. That bracelet has to have vibration functionality that can be triggered by a supervisor on demand. The use case of receiving a notification is therefore simulated by a supervisor. That kind of prototype has properties of both a high-fidelity prototype as well as a low-fidelity prototype. It is already much more than a simple prototype that only simulates behavior, but triggering vibration alarms has to be done by a supervisor still. Furthermore, the bracelet itself will be built as simple as possible. For instance, the material of the bracelet will by no means be the one that should be used in a final product. With certain aspects already very defined and others simulated, the used prototype qualifies as a "vertical prototype".

   The different parts of the prototype will be described in detail in Chapter 5 *Technical Implementation*, with individual sections like 5.3 *Building a Bracelet*, 5.6 *iOS Application*, or 5.7 *Java Backend*.

3. **Evaluation of the prototype**

   This step is about getting user feedback to eliminate design flaws. Also, usability and design issues should be discussed and then implemented in further development. An important part of this step is to evaluate which different vibration notifications are easily distinguishable by test persons. It will help to answer the important question of how much complexity should be put into different vibration patterns.

   Principles of User-Centered Design (UCD) will be used to evaluate the prototype. UCD places a lot emphasis on design that is easily understood by test users. To evaluate the usability, a questionnaire with both open questions and multiple-choice questions will be used. In Chapter 6 *Hypotheses and User Tests* the structure of the questionnaire will be described and explained, while Chapter 7 *Result Evaluation* will present the results.

   This kind of evaluation can be classified as a "mixed methods research" approach. Alan Bryman describes that the term is supposed to express that "both quantitative and qualitative research should involve a mixing of the research methods involved and not just using them in tandem" [50, p. 628]. A questionnaire that can be completed by test persons without supervision would usually be linked to quantitative research. Open questions and interviews are typical for qualitative research however. The choice to take a mixed approach has been made because some questions had easily quantifiable answers, whereas other questions were meant to challenge theories and to open up new pathways by not restricting the thinking process of the test persons.

4. **Analysis and conclusion**

   In this step, the literature review and evaluation of technologies (see Point 1) will be combined with and compared to the outcomes of the prototype.

   Possibilities for further development will be discussed, based on user feedback in Chapter 8 *Analysis*. An example could be alterations in the vibration patterns or user interface improvements. User management could be added to enable message sending between multiple participants and to secure messages via user authentication and authorization.

   An analysis of the main findings of the thesis in regard to the main research questions (see 1.2.1 *Research Questions*) will be documented in detail as well as possible further steps of improvements and final conclusions.

CHAPTER 5

Technical Implementation

This chapter consists of a detailed description of the implementation process of building a vibrating bracelet and the accompanying parts. First of all, the requirements will be described. Afterwards, the development process will be outlined.

5.1 Development and Implementation

The high-level result of this part is a vibrating bracelet that is able to inform users about various messages. The bracelet and the development it entails shall be called Discrete notifications via vibrotactile signals (Dinovis) from here on. Distinguishable vibration patterns will be evaluated and implemented in a prototype which will consist of the components described below and outlined in Figure 5.1.

5.1.1 Components

This is a short description of the components involved in the development and implementation.

1. **Server component**

   The server component contains the notification logic and offers an open RESTful API to create notifications which will be pushed to the corresponding iOS device.

   With the server component, it will be possible to create predefined notification patterns or entirely customized patterns.

2. **iOS component**

   The iOS component acts as a receiver: It enables the user to receive notifications which will be pushed to the notification device.

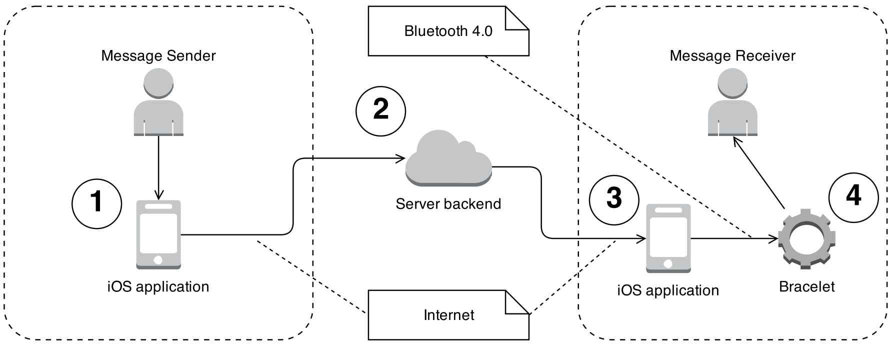


Figure 5.1: Communication flow of Dinovis in detail:

Point 1: The sender creates a message in his or her iOS application and sends it to a selected receiver.

Point 2: The server back end Application Programming Interface (API) takes the request and pushes a message to the iOS application of the selected receiver.

Point 3: The receiver's iOS application processes the message and sends a vibration alert to the corresponding bracelet.

Point 4: The bracelet begins to vibrate, notifying the receiver.

3. **Notification device**

   In the scope of this thesis a vibrating bracelet will be built to be the notification device that connects to the iOS component via Bluetooth and vibrates whenever a notification is received (see Figure 5.2). The hardware components needed to create such a bracelet will be evaluated and a prototype will be built. It will contain a Bluetooth 4 component, a vibration motor, and a battery.

   Research of perception of vibration strength and intensity [51, 52] will be considered when building the vibrating bracelet.

5.1.2 Development Steps

The development process itself consisted of three parts:

1. The largest part being the development of a physical bracelet that has vibration capability. This part includes programming of said bracelet to react so incoming messages.

2. Secondly, the "logical counterpart" to the vibrating bracelet: An iOS application that communicates with the bracelet via Bluetooth by transmitting encoded vibra-

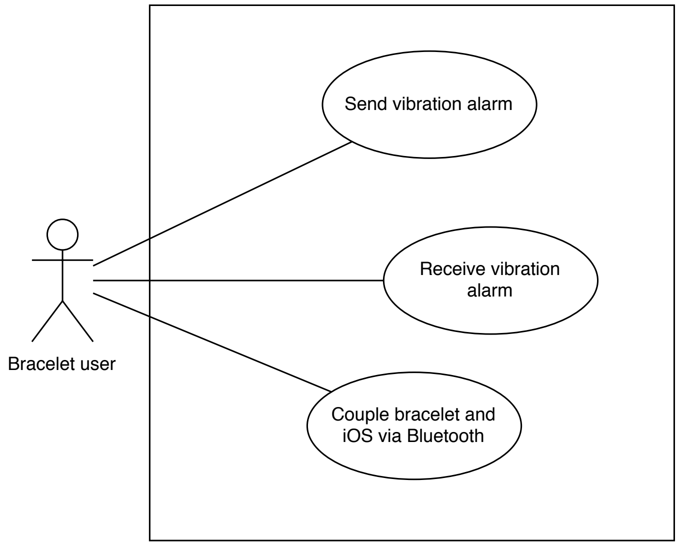


Figure 5.2: Use cases for the vibrating bracelet.

tion signals which the bracelet translates to corresponding vibration signals. This application is designed with an open interface for third-party applications in mind.

3. Thirdly, a Java backend that demonstrates how a web application can be used as a "third-party application" to control the vibrating bracelet.

Each of these parts will be described separately, as long as it is not mandatory to explain multiple of those parts in one place for reasons of understandability.

5.1.3 Requirements

The idea of a vibrating bracelet was born from the requirement to have a discrete possibility to inform care-takers in case of emergency of one of their patients.

One key requirement has been stated to be that the person who has to be notified should not be hindered in their daily activities. Such activities include grocery shopping (i.e., no free hands), sport (i.e., inability to have a cell phone nearby), or being somewhere where noise would be inappropriate. Another key requirement was the necessity to be "discrete", meaning that a user of whatever notification device should not have an obvious technical device. Especially not a device that is immediately recognizable as some sort of "emergency notification device".

Choice of Device

This section should provide a very brief summary of the thoughts that led to the development of a vibrating bracelet specifically and not some other device with notification capabilities.

It has been clear very early on that a wearable-device would be a good option. At this point, the exact "flavor" of the device was not yet decided, just that it had to be something to be worn. For any possible wearable-device, the following senses could be used:

1. Sight: Changing color or blinking could be options here, to inform a wearer of incoming messages (comparable to "Damage", see 2.2 *Further research concerning public and subtle notification devices*.
2. Hearing: An audible signal could inform about messages.
3. Touch: Here, vibration seemed to be a very interesting option.

The hearing sense has been discarded as an option very quickly because it hardly fulfills the necessity of discreetness. Sight has been in consideration a bit longer, but it has been discarded as an option as well. Using blinking or color-coded signals would have meant a necessity for a potential device to always be in the line of sight. This seemed very unpractical and too public.

In the end, a vibrating bracelet seemed to fit the requirements the best:

1. It would be discrete because only the wearer would feel an incoming message. Even though a vibration might be heard by nearby persons, it still seemed far more discrete than any visual or auditory cue.
2. The design could be made in a way that it would look "fashionable" and not too technical.
3. A vibrating bracelet would fulfill the requirement of not needing free hands.
4. Furthermore, a vibrating bracelet could be worn while doing sportive activities.

5.2 Vibrating Bracelet

This is a description of how the vibrating bracelet has been built and what the challenges were. Furthermore, the used technologies shall be explained and brief introductions shall be made.

5.2.1 Selecting the Hardware

This section describes the selection of the hardware components that were used when building the vibrating bracelet.

The most challenging part of that process was the selection of a fitting ARM microcontroller. In this regard, the following points were of utmost importance:

- Easy programmability.
- Small enough to fit into a bracelet.
- Powered by battery.
- Bluetooth Low Energy capability.
- Ability to connect and power a vibration motor.

The evaluation came to the conclusion that RFduino [53], which is a very small Arduino, fits these criteria perfectly. Both will be described shortly.

Arduino

Arduino is both a family of microcontrollers and a software development environment that uses C or C++ to program said microcontrollers [54]. Arduino makes it easy to interact with the physical world via sensors and actuators. Sensors could be described as inputs for the Arduino, whereas actuators could be described as outputs. Here are a few examples of things that can be measured by sensors: Temperature, humidity, sound, acceleration, and pressure. Examples for actuators would be: Light-Emitting Diodes (LEDs), motors (e.g., servos or vibration motors) and speakers.

RFduino

RFduino advertises their microcontroller as: "A finger-tip sized, Arduino compatible, wireless enabled microcontroller, low cost enough to leave in all of your projects!" [55]

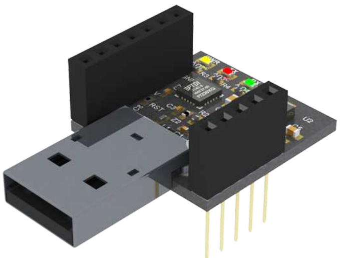


Figure 5.3: RFD22121 USB Shield for RFduino [56].

Just like the various Arduino boards [57], RFduino is programmable via the Arduino-IDE [58]. Arduino programs are written in either C or C++. The Arduino IDE offers a lot of libraries to make programming easier and faster. Such libraries include functionality to easily read and write to "permanent" storage, connecting to the internet, or controlling servo motors [59]. The RFduino comes with a set of additional libraries, including libraries to connect devices via Bluetooth (RFduinoBLE). The RFduino software also includes samples to help getting started more easily. Those examples include programs starting from simple "blink"-applications (where a LED blinks continuously), to more complex

(a) RFD22301. (b) Vibration motor. (c) Battery holder. (d) Coin cell.

Figure 5.4: List of hardware parts for the vibrating bracelet [60, 61, 62, 63].

examples, where an iOS application is able to control the LED color of the RFduino by connecting via Bluetooth. The latter one is called "ColorWheel" and has been used as a base for the Dinovis application developed for this thesis.

An RFduino microcontroller offers different input and output pins that can be accessed programmatically. Besides the microcontroller, RFduino offers different so-called "shields" that offer specific functionality. Those "shields" offer easy connection capabilities with their long connection pins which allow easy stackability of different shields. Here a few examples of the capabilities of different shields:

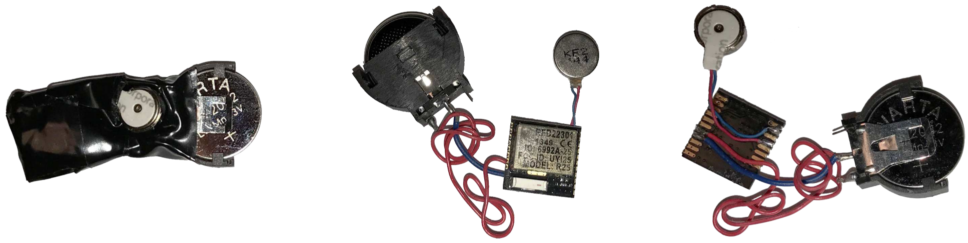
- The "USB Shield" (see Figure 5.3) is the most mandatory one and is required to load code onto the RFduino.
- The "RGB / Button Shield" has a LED with separate (output) channels for red, green, and blue (GPIO 2 to GPIO 4) and (input) channels for button A and B (GPIO 5 and GPIO 6).
- The "Coin Battery Shield" is powered by a CR2032 coin cell battery and powers the RFduino. It has an output voltage of 2V - 3V and an output current of 25mA.

All the above shields were used in the development and prototyping process of the vibrating bracelet.

5.3 Building a Bracelet

The developed vibrating bracelet consists of four parts (not counting wires):

- RFD22301 [60]: A small version of RFduino without shield (see Figure 5.4a).
- A flat coin vibration motor from Parallax [61] (see Figure 5.4b).
- A coin battery cell holder from Harwin [62] (see Figure 5.4c).
- A 2032 coin cell with 3V and 220mAh [63] (see Figure 5.4d).



(a) Bracelet hardware protected by electrical tape.

(b) Front view of the unprotected bracelet hardware.

(c) Rear view of the unprotected bracelet hardware.

Figure 5.5: Images of the developed bracelet prototype hardware.

Figure 5.4 shows images of the individual hardware parts. Those parts were then soldered together.

Figure 5.5 shows various pictures of the hardware prototype of the developed bracelet. Subfigure 5.5b and 5.5c show a much longer red cable (power) in comparison to the blue cable (ground). This is due to the fact that a power switch could be added easier that way later on. A power switch would have to go between the battery and the RFduino. The red cable would have to be split and the power switch would go between the new ends of the red cable. With the given length of the red cable, there would easily be enough room to add a power switch.

Without the power switch, the bracelet is started by putting in a battery, and shutdown by removing a battery again.

The bracelet band: The hardware of the bracelet was then put into a silicone bracelet called “PocketBand” [64]. The wrapped hardware (see Figure 5.5a) easily fit into the pocket of the silicone bracelet. As seen in the picture, the vibration motor is not wrapped in electrical tape. When putting the bracelet hardware into the PocketBand, it was important to make sure that the vibrating motor faced downwards (towards the wrist). This increased the perceived vibration intensity.

Figure 5.6 showcases the bracelet material. Figure 5.6b shows a few different sizes and colors of PocketBands. In Figure 5.6a a PocketBand including the bracelet hardware can be seen.

(a) PocketBand with included hardware. (b) Different sizes and colors of PocketBands.

Figure 5.6: Prototype bracelet bands for the vibrating bracelet with and without hardware.

5.4 Arduino Programming

This section describes the development process of the Arduino program and the deployment of it.

First, the technology will be introduced. This includes the Arduino IDE, the structure of Arduino programs ("sketches"), Arduino and RFduino libraries, as well as shortcomings and limitations of Arduino programming.

Afterwards, the development process in the context of this thesis will be described and explained in detail.

5.4.1 Technology

As described in Section 5.2.1 ("RFduino"), the program for the vibrating bracelet is written in C, using the Arduino IDE.

The Arduino IDE is a cross-platform application written in Java. The Arduino IDE includes a source code editor (with features such as syntax highlighting), a compiler, and a serial monitor [65, p. 10].

Arduino programs are often referred to as "*sketches*" and always contain two methods: `setup` and `loop`. Code that only needs to be executed once (at the beginning), goes into the `setup` method, whereas code that needs to be executed continuously has to be put into the `loop` method.

Setup

The setup function is an initialization routine that is typically used to initialize pins as `INPUT` or `OUTPUT`, setting a baud rate for serial communication, or to set up properties of additional libraries, such as libraries for Bluetooth support.

Arduino sketches must always have a setup function [66, p. 18]. Even if nothing has to be set up, the setup function has to be present or an error will be generated.

Arduino pins can either be set as `INPUT` or `OUTPUT` via the `pinMode()` function. In contrast to Arduino, RFduino has all pins defined as IO (GPIO) and therefore all pins can be both `INPUT` or `OUTPUT`, though not at the same time.

```
void setup() {

  // pin 2 on the RGB shield is the red led
  int redLed = 2;

  // pin 5 on the RGB shield is button 1
  int button = 5;

  void setup() {

    pinMode(redLed, OUTPUT);
    pinMode(button, INPUT);

    // more code here
  }
```

Listing 5.1: Example of a setup() method.

Listing 5.1 shows an example configurations of a `setup()` method.

This code example first defines two integers with saying names: `redLed` and `button` [65, p. 7]. Afterwards, the `pinMode()` function defines pin 2 (`redLed`) to be an `OUTPUT` and pin 5 (`button`) to be an `INPUT`. Because of this assignment, it is possible to write to `redLed` (i.e., turn the red led on and off) and read from `button` (i.e., react when the button is pushed). In more technical terms: Pin 2 will be able to provide current to external devices or circuits on-demand and pin 5 will be ready to read currents from devices connected to it.

Serial Monitor

Arduino sketches are able to use serial communication when connected to a computer via USB cable [66, p. 16]. The communication can be monitored with a "serial monitor" on a computer. This serial monitor is included in the Arduino IDE and is very useful when debugging Arduino sketches, as logging can be done via serial communication.

```
  void setup() {

    Serial.begin(9600);
    Serial.println("Starting up..");

    // more code here
  }
```

Listing 5.2: Example of setting up serial communication.

Listing 5.2 shows how in order to set up serial communication, the speed at which Arduino sends data has to be specified [66, p. 38]. The so-called “baud rate” of has to be the same on Arduino and host computer (serial monitor) in order for them to understand one another.

After setting up serial communication, the following two functions can be used to send data to the serial monitor: `Serial.print` and `Serial.println`. Where the former prints data without a new line at the end, the latter prints a new line at the end of the given string data.

Loop

After uploading a sketch or whenever an Arduino board is powered on, the setup method gets executed once. After that, the code in the loop method is called. When the loop reaches its end, the execution goes back to the start of the loop [54, p. 24]. See Listing 5.3 for an example of a `loop` function (taken from [67]).

```
// the loop function runs over and over again forever
void loop() {
   digitalWrite(13, HIGH);    // turn the LED on (HIGH is the voltage level
       )
   delay(1000);               // wait for a second
   digitalWrite(13, LOW);     // turn the LED off by making the voltage LOW
   delay(1000);               // wait for a second
}
```

Listing 5.3: Example of a loop() method.

Experienced C/C++ programmers might miss the main() function. The Arduino environment hides the method by creating an intermediate file that includes the sketch code and the following statements, as outlined in Listing 5.4 (taken from [54, p. 25]).

```
int main(void)
{
   init();
   setup();
   for (;;)
   loop();
   return 0;
}
```

Listing 5.4: Hidden main function.

As seen in this code example (Listing 5.4), the `init()` method gets called first. This method initializes the Arduino hardware. Afterwards the `setup()` method gets called, followed by an infinite loop over the `loop()` function. The return statement never gets called.

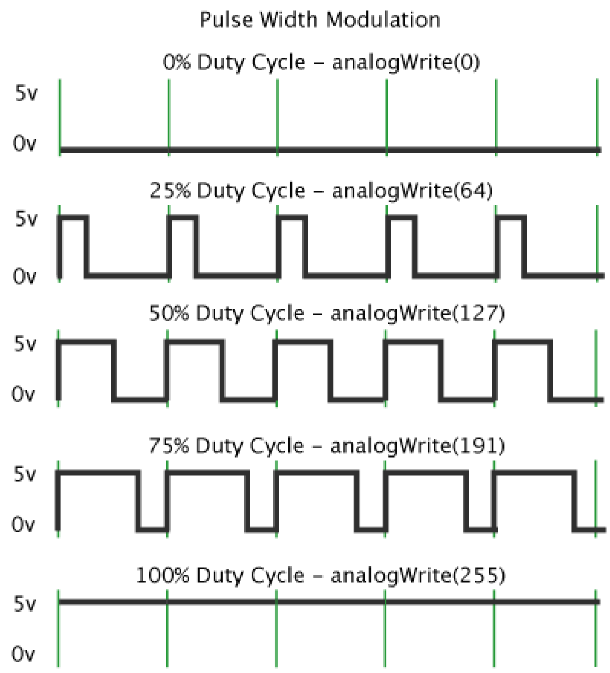


Figure 5.7: Pulse Width Modulation [68].

Arduino sketches are not limited to these predefined methods. Other methods can be implemented and would usually be called by the `loop()` method.

Digital and analog output

Digital and analog output both have in common that they output voltage to a specified pin. There are fundamental differences between those output types however:

1. **Digital output**

   A digital output is done via the `digitalWrite` method (see [69]) which sets voltage on a pin to either HIGH (5V) or LOW (0V). Those two states are defined as constants in Arduino (see [70] for more information).

   A LED connected to the specified pin would have its light turned on or off with those respective states.

   For a pin to respond to the `digitalWrite` method, the `pinMode` has to be set to `OUTPUT` in the `setup` method [54, p. 241].

2. **Analog output**

   The `analogWrite` method (see [71]) makes it possible to assign values between 0 and 255 to a pin. A technique called Pulse Width Modulation (PWM) is used to create intermediate states between on and off. This is done by turning the power

i = 0	i = 1	n intensity/duration-pairs	
		1 ≤ n ≤ 4	
repetition mode	number of repetitions	i = n * 2	i = n * 2 + 1
		vibration intensity (0-255)	vibration duration (ms)

Figure 5.8: Encoded vibration pattern structure.

on and off so quickly that our human senses do not perceive those separate on and off states as two alternating states anymore, but as just one continuous state. This means that an `analogWrite` signal with a value less than 255 sent to anLED would be perceived as permanently on, but with less intensity [65, p. 65]. See Figure 5.7 for illustration.

5.5 Dinovis Arduino Application

The Dinovis application has been developed to run on an RFduino (see Section 5.2.1). It uses the RFduinoBLE library (see [72]) to receive encoded vibration patterns from devices connected to the RFduino via Bluetooth Low Energy.

5.5.1 Pattern Encoding

Dinovis is designed to receive and execute vibration signals. PWM (see Section 5.4.1) is used to output different vibration intensities, with intensities ranging from 0 (= no vibration) to 255 (= maximum vibration).

The RFduinoBLE library has a method called `RFduinoBLE_onReceive(char *data, int len)` which is able to receive an array of data with a defined length. However, this method is only able to receive a limited amount of data, which made it impossible to transmit longer vibration signals without a sort of encoding.

To create longer vibration signals, the data array has been created so that it includes a repetition mode and a number of repetitions, followed by a variable number of intensity and duration pairs.

The following description explains the individual parts of of the data array (see Figure 5.8):

Repetition mode

The repetition mode can be a number between 0 and the total length of the array minus 2. Whenever the number is either 0 or $array.length-2$, all intensity/duration-pairs get repeated. Otherwise, only the first X intensity/duration-pairs get selected to be repeated, where X is repetition mode.

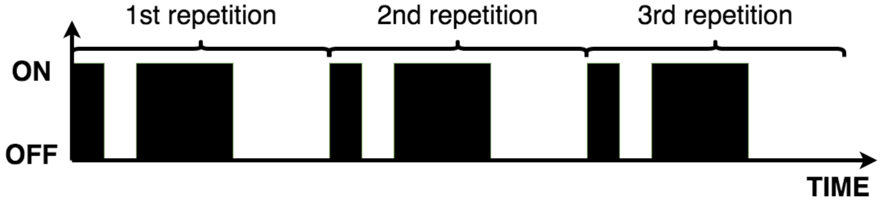


Figure 5.9: Example of a vibration signal with alternating vibration lengths.

Number of repetitions

The number of repetitions can be an integer number between 1 and 5. This number determines how often the selected intensity/duration-pairs get "played". This means that at most, 20 intensity/duration-pairs can be executed $(4 * 5)$.

Note: Whenever a vibration pattern with more than those 20 intensity/duration-pairs needs to be sent, the vibration pattern should be split into multiple messages. RFduino will queue incoming messages and will execute the vibration patterns right after one another, without any pause.

Intensity/duration-pairs

Vibrations "played" by the vibrating bracelet always have a vibration intensity (between 0 and 255) and a vibration duration (in milliseconds). Vibration should be followed by a pause or a very significant difference between two successive intensity/duration-pairs. Otherwise, two intensity/duration-pairs are very hard to distinguish.

Note: This follows the recommendation by Saket et al. [11] to design vibration patterns with alternating on/off sequences.

5.5.2 Example and Explanation

This section explains how a vibration pattern is received and processed with relevant source code parts of the Dinovis Arduino application (see [73] for full source code).

Listing 5.5 shows the log output after receiving a vibration signal. The log output is taken from the serial monitor and is shown after receiving a vibration signal that has alternating on/off cycles of different lengths. In this example, the vibration signal starts with an intensity of 255 for 250ms, followed by a 250ms pause (with intensity 100, see explanation in "Subsection Why intensity 100 instead of 0 for OFF?"), followed by a full vibration for 600ms which is again followed by a pause of 600ms. This whole signal is then repeated three times. See Figure 5.9 for illustration.

```
Data with len 10 just came in
Data: 0 3 255 25 100 25 255 60 100 60
Repetition mode: 0, repetitions: 3
Intensity/duration pairs: 4
* Repeating ALL 4 entries *
### REPETITION 1 of 3 ###
Intensity of 255 for 250ms.. done
Intensity of 100 for 250ms.. done
Intensity of 255 for 600ms.. done
Intensity of 100 for 600ms.. done
### REPETITION 2 of 3 ###
Intensity of 255 for 250ms.. done
Intensity of 100 for 250ms.. done
Intensity of 255 for 600ms.. done
Intensity of 100 for 600ms.. done
### REPETITION 3 of 3 ###
Intensity of 255 for 250ms.. done
Intensity of 100 for 250ms.. done
Intensity of 255 for 600ms.. done
Intensity of 100 for 600ms.. done
```

Listing 5.5: Logging output after receiving a vibration signal.

Why intensity 100 instead of 0 for OFF?

The decision to use intensity 100 instead of 0 for the OFF-state was caused by a technical limitation. Due to the fact that the vibrating motor used by the vibrating bracelet is not able to instantly go from no rotation (i.e., no vibration) to full rotation (i.e., maximum vibration), short vibrations (i.e., 250ms) did not reach their full momentum fast enough. This had the effect that short vibrations felt weaker than longer vibrations. To lessen this issue, it turned out to be better to never fully stop the vibrating motor during vibration pauses. This is the reason, why the attached log file (Figure 5.5) switches between full intensity (255) and an intensity of 100.

Why duration 25 instead of 250?

The log output shows the following line:

```
Data: 0 3 255 25 100 25 255 60 100 60
```

As seen in Figure 5.8 (see Section 5.5.1), the third, fifth, seventh, and ninth numbers represent the vibration duration.

The `RFduinoBLE_onReceive` method uses a `char` array to transmit data. This data type is one byte long, just as the data types `byte` and `uint8_t` which are one byte long as well (see [54, p. 26]). The latter two are the same in Arduino.

Due to the fact that those data types are all one byte long, the maximum number they can represent is 255 which is not enough for longer vibration durations (e.g., 600ms). For this reason, one-tenth of the duration gets transmitted and the received numbers have to be multiplied by ten to get the correct amount of milliseconds again. This leads to the inability to send vibration durations of under 10 milliseconds.

Relevant code parts

Listing 5.6 shows the relevant code parts of the `RFduinoBLE_onReceive` method. Parts that are irrelevant in this example, as well as the repetition loop, were omitted. Such parts are marked by three dots. The whole source code can be found here [73].

```
void RFduinoBLE_onReceive(char *data, int len) {

   uint8_t repetitionMode = data[0];
   uint8_t numberOfRepetitions = data[1];

   int pairs = (len - 2) / 2;

   uint8_t intensity;
   uint8_t duration;

   printDebugInformation(data, len, pairs, repetitionMode,
      numberOfRepetitions);

...

   // are we repeating all or only parts?
   boolean repeatAll;
   if (repetitionMode == 0 || repetitionMode >= pairs) {
      repeatAll = true;
   ...
   }
...

   // repetition loop goes here

...

}
```

Listing 5.6: Shortened code example of the Dinovis Arduino application, without the repetition loop.

Explanation of Listing 5.6
The following description will explain individual parts of Listing 5.6.

Repetition mode and number of repetitions

```
3   uint8_t repetitionMode = data[0];
4   uint8_t numberOfRepetitions = data[1];
```

In line 3 and 4, the repetition mode and number of repetitions get extracted from the data array. The char value is interpreted as unsigned integer (`uint8_t`) and therefore as a number.

Intensity/duration-pairs

```
int pairs = (len - 2) / 2;

uint8_t intensity;
uint8_t duration;
```

The number of intensity/duration-pairs (called `pairs` here) is calculated according to Figure 5.8.

The two variables `intensity` and `duration` are declared as `uint8_t` data types, to be used later on.

Repetition mode

```
// are we repeating all or only parts?
boolean repeatAll;
if (repetitionMode == 0 || repetitionMode >= pairs) {
   repeatAll = true;
...
}
```

Here, the distinction between repeating the whole pattern of intensity/duration-pairs or just repeating some of them is made. As described above, parts only get repeated if the repetition mode is greater than zero and lesser than the total number of intensity/duration-pairs. In case those conditions are not met, the intensity/duration-pairs are repeated as a whole. This case can be seen in the example logging output from Listing 5.5.

Repetition loop

```
   /* REPEATING ALL CODE */
   if (repeatAll) {
      for (int j = 0; j < numberOfRepetitions; j++) {

         Serial.print("### REPETITION ");
         Serial.print(j+1);
         Serial.print(" of ");
         Serial.print(numberOfRepetitions);
         Serial.println(" ###");

         for (int i = 2; i < len; i++) {
            intensity = data[i];
            duration = data[++i];

            setIntensityForDuration(intensity, duration);
         }
      }
   }
```

Listing 5.7: Repetition loop.

The code part shown in Listing 5.7 is executed when all intensity/duration-pairs have to be repeated. In those loops, the intensity/duration-pairs get extracted from the data array and passed to the method `setIntensityForDuration` which sets a specified vibration intensity to be executed for a set duration (see next point).

The code also shows one problem when printing to the serial monitor: It is not possible to concatenate static string output and variable output. For this reason, there are multiple `Serial.print` lines which all get appended to one line in the serial monitor until the call of the `Serial.println` method.

```
void setIntensityForDuration(uint8_t intensity, uint8_t duration) {

  int dur = duration * 10;

  Serial.print("Intensity of ");
  Serial.print(intensity);
  Serial.print(" for ");
  Serial.print(dur);
  Serial.print("ms.. ");

  analogWrite(vibrationMotor, intensity);
  delay(dur);
  Serial.println("done");
}
```

Listing 5.8: This method is used to set a vibration intensity for a specified duration.

Setting a vibration intensity for a set duration

Listing 5.8 shows how the `setIntensityForDuration` method takes care of the multiplication of the given duration (see Subsection 5.5.2 *Why duration 25 instead of 250?*). Afterwards, the pin that is connected to the vibration motor gets set to the specified intensity via the `analogWrite` method. As described in Subsection 5.4.1 *Digital and analog output*, `analogWrite` uses Pulse Width Modulation.

5.6 iOS Application

This section will describe the development of the iOS application and the technology that has been used.

The iOS application uses Bluetooth Low Energy (BLE) to connect to the vibrating bracelet. When connected, the iOS application is able to send encoded vibration signals to the bracelet. Furthermore, the iOS application is able to receive push notifications via the Apple Push Notification service (APNs). Those push notifications again contain encoded vibration patterns which the iOS application forwards to the vibrating bracelet.

The following sections will describe all the above in detail.

5.6.1 Technology

This section will explain the underlying technology that has been used when developing the iOS application.

Apple Push Notification Service

The APNs has proven to be a reliable way to transmit data to iOS. At first, it seemed unlikely that APNs alone would suffice. An effort has been made to try and use a socket connection instead of APNs at first. The thought was that such a connection would guarantee reliable and instant communication between the iOS application and the RFduino application. However, the problems started as soon as the iOS application went to background: iOS applications do not permit background executions of applications (in most cases, see [74] for exceptions) and therefore, the socket connection closes shortly after the iOS application goes to background [75].

The APNs [76] on the other hand was very reliable in tests and therefore the method of choice for the prototype application.

APNs technical details: APNs is used to transmit secure remote notifications to specified iOS, tvOS, or OS X/macOS devices [76]. There are four components involved in the process of delivering notifications (see Figure 5.10):

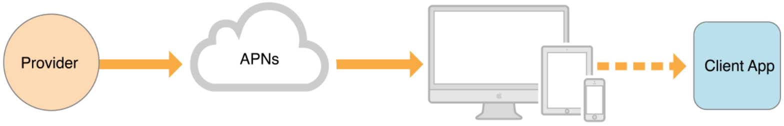


Figure 5.10: Path of a Remote Notification [76].

Provider: The provider is the component that composes notifications and sends them to the APNs (see Item "APNs" below). All notifications have a payload that consists of JavaScript Object Notation (JSON) formatted data. The payload has several defined standard fields under the reserved key `aps` which will be explained later on. One or more of those fields can be present under the `aps` key. Those standard fields include an `alert` message to be displayed (with localization options), the so-called "`badge`", which is the little number in the corner of the app icon, the name of a `sound` file to be played, or a notification called `content-available` which is a signal for the application that content is available to be received by a completion handler (see [77] for more information).

Aside from those standard fields, custom key and value pairs can be added as notification payload.

Along with that data, a token is sent to the APNs. This token is a unique identifier for each device and therefore acts as a unique address, with the APNs being the notification dispatcher.

The provider has to be implemented using the APNs Provider API [78].

APNs: The APNs is a server component implemented by Apple. It uses encrypted communication to send data to specified devices. The device token provided by the provider (see "Provider" above) is decrypted by the APNs and contains the device ID. With that, the APNs is able to dispatch a notification to the correct recipient device.

Device and Client Application: An Apple device can register for push notifications on a per-application basis. A push notification enabled application receives the device token from the device it is installed on which in turn receives its token from the APNs. After getting the device token, the application has to pass it to the provider which stores the token and is able to send notifications as needed from that point on (see Figure 5.11).

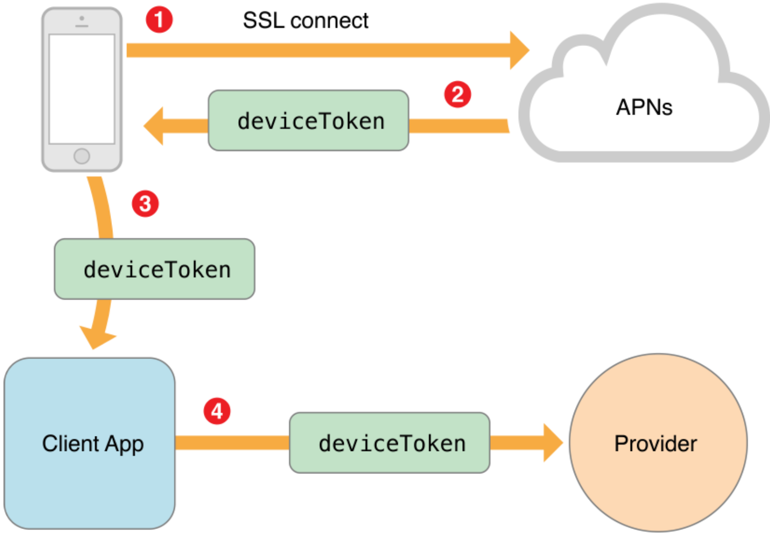


Figure 5.11: Device token exchange [76].

iOS RFduino libraries

RFduino offers iOS example applications on GitHub [79] under the GNU's Not Unix! (GNU) Lesser General Public License 2.1 [80]. Included are classes that handle the connection to an RFduino BLE device.

Most notable functionality of the iOS RFduino libraries

- A fully implemented screen that scans for available BLE devices in range and lists them, including all available information, such as device name or advertisement data. On this screen, the user may select one of those devices to connect to (see Figure 5.12).
- A bidirectional connection between a BLE device and the iOS application, with capabilities to react to incoming messages and to send outgoing messages (as byte stream).
- A number of handlers and helper methods, including handlers for connection and disconnection events, as well as the discovery of new devices in range, or methods to determine the BLE support and capabilities to react accordingly.

5.6.2 Implementation

This section will describe the prototype iOS application that has been developed to communicate with the vibrating bracelet (see Section 5.2 *Vibrating Bracelet*), to receive and process Apple Push Notifications, and to evaluate the user tests (see Chapter 6 *Hypotheses and User Tests*).

All of those aspects have been developed into one iOS application. While sending and receiving Apple Push Notifications does not require user interface interaction, user test evaluation is very reliant on the user interface. Because of that, the user interface and application flow of the iOS application are closely coupled to the user test, while still providing all functionality to receive Apple Push Notifications. Both the technical aspect of sending and receiving notifications, as well as the user test evaluation will be described in detail separately.

Push notification handling

Push notification handling is done by the `AppDelegate` class which is part of each iOS project.

```
* A push notification arrived:
{
    aps =     {
        alert = "Vibration alarm #1 has arrived";
    };
    duration1 = 100;
    duration2 = 50;
    duration3 = 150;
    intensity1 = 250;
    intensity2 = 0;
    intensity3 = 255;
    repeatMode = 0;
    repeats = 1;
}
```

Listing 5.9: Logging output when receiving an Apple Push Notification.

The `UIApplicationDelegate` protocol is implemented by `AppDelegate` and defines important methods to communicate between applications and the system. Startup code, application state handling, and notification handling are responsibilities of `AppDelegate` (for more information, see [81]). The method used in Listing 5.10 is `application:didReceiveRemoteNotification:` which is one of two methods that are used for remote notification handling. The second method is called `application:didReceiveRemoteNotification:fetchCompletionHandler:` and should be the choice for future development, as it is able to process incoming notifications even in background (see [82]).

Listing 5.10 shows how the incoming `userInfo` message is handled by the Dinovis iOS application. As described in “APNs technical details:”, Apple Push Notifications always have a key called `aps`. In Line 7 (Listing 5.10) the `alert` message is extracted from the `aps` key and the message is logged. Listing 5.9 shows the JSON formatted logging output.

```
1  /*
2   * This method gets called automatically when a push notification arrives.
3   */
4  -(void)application:(UIApplication *)application didReceiveRemoteNotification:(
       NSDictionary *)userInfo
5  {
6      NSLog(@"* A push notification arrived: \n%@", userInfo);
7      NSString* alertValue = [[userInfo valueForKey:@"aps"] valueForKey:@"alert"];
8      NSLog(@"* Alert value: '%@'", alertValue);
9
10     UINavigationController *navigationController = (UINavigationController*)_window
           .rootViewController;
11
12     NSLog(@"Controller count: %lu", (unsigned long)navigationController.
           viewControllers.count);
13
14     if (navigationController.viewControllers.count > 1) {
15
16         BaseViewController* baseViewController = (BaseViewController*)[
               navigationController.viewControllers objectAtIndex:1];
17
18         [baseViewController processNotification:userInfo];
19     } else {
20         NSLog(@"** No AppViewController found. Unable to process notification! **");
21     }
22 }
```

Listing 5.10: Handler for receiving remote notifications.

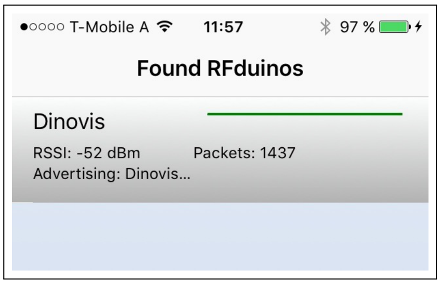


Figure 5.12: Screen that shows discovered Bluetooth devices.

The first screen of the application (see Figure 5.12) has the purpose of selecting the vibrating bracelet to connect to. This screen is represented by the `ScanViewController` which of course is a `UIViewController`. This means that the `ScanViewController` is always at position 0 in the list of `UIViewController`. Before connecting to a vibrating bracelet, the encoded vibration pattern of a notification does not have to be processed, as there is no vibration device to execute any vibration pattern. Whenever there is more than one `UIViewController`, it means that the `ScanViewController` has been exited by successfully connecting to a vibrating bracelet. For this reason, there is a check for the number of `UIViewController` in Line 14 (Listing 5.10).

Line 16 (Listing 5.10) gets the `BaseViewController` which holds common functionality for all implementations of `UIViewController` within the project. In this project, the `BaseViewController` is always at index 1 of the `UIViewController`. This is guaranteed in this project because all screens after the first screen inherit from `BaseViewController`, resulting in that screen to be instantiated first every time. Afterwards, the `processNotification:userInfo` method is called in Line 18 (Listing 5.10).

The `processNotification:userInfo` method can be seen in Listing 5.11. In that method, a previously received notification is parsed and the values are written into an `uint8\_t` array which is the expected format for data transfer to an RFduino over Bluetooth (i.e., the vibrating bracelet). Since the array needs to have the size allocated, Lines 10 to 15 (Listing 5.11) check the number of entries of the received notification. In Line 17 (Listing 5.11) the array named `signal` gets allocated with the `numberOfEntries`. As described in Section 5.5.1 *Pattern Encoding*, the vibration signal always has an even number of entries, as the vibration signal consists of intensity/duration-pairs. For this reason, `numberOfEntries` will never be an uneven number.

```
1  /*
2   * The delegation handler for push notifications in AppDelegate
3   * calls this method when a push notification arrives.
4   */
5  -(void)processNotification:(NSDictionary *)userInfo
6  {
7     int numberOfEntries = 0;
8     _messagesTextView.text = userInfo.description;
9  
10    if ([userInfo valueForKey:@"intensity4"] != nil) {
11       numberOfEntries = 10;
12       ALog(@"FOUR elements, number of entries: %d", numberOfEntries);
13    } else if ([userInfo valueForKey:@"intensity3"] != nil) {
14       ... // more code here
15    } else { ALog(@"** NO ELEMENT **"); return; }
16 
17    uint8_t* signal = malloc(numberOfEntries*sizeof(uint8_t *));
18 
19    switch (numberOfEntries) {
20       case 10:
21          signal[9] = [[userInfo valueForKey:@"duration4"] integerValue];
22          signal[8] = [[userInfo valueForKey:@"intensity4"] integerValue];
23       case 8:
24          ... // more code here
25       case 4:
26          signal[3] = [[userInfo valueForKey:@"duration1"] integerValue];
27          signal[2] = [[userInfo valueForKey:@"intensity1"] integerValue];
28          signal[1] = [[userInfo valueForKey:@"repeats"] integerValue];;
29          signal[0] = [[userInfo valueForKey:@"repeatMode"] integerValue];;
30          break;
31       default:
32          ALog(@"** Default case - something went wrong! **"); break;
33    }
34    [self sendPattern:signal withNumberOfEntries:numberOfEntries];
35    free(signal);
36 }
```

Listing 5.11: Processing a received notification.

From Line 19 to 33 (Listing 5.11), the `numberOfEntries` are processed in a `switch` and the values of the `signal` array are filled accordingly. A descending order without `break` commands is used to effectively assign all values of the `NSDictionary` to the array. Getting the JSON formatted data within an `NSDictionary` is very convenient, as each value can be directly accessed via key.

Line 34 (Listing 5.11) calls the `sendPattern:withNumberOfEntries:numberOfEntries:` method which can be seen in Listing 5.12. Apart from printing debug information, the method creates an `NSData` data object which is an "object-oriented wrapper for byte buffers" [83]. The data is then sent in Line 17 (Listing 5.12), using the `RFduino` library described in Section 5.6.1 *iOS RFduino libraries*.

```
1  /*
2   * This method sends data to the RFduino.
3   */
4  - (void)sendPattern:(const uint8_t[]) patternArray withNumberOfEntries:(int)
       numberOfEntries
5  {
6      ALog(@"sendPattern. Number of entries: %d", numberOfEntries);
7
8      for (int i = 0; i < numberOfEntries; i++) {
9
10         ALog(@"patternArrayEntry[%d]: %hhu", i, patternArray[i]);
11     }
12
13     NSData *data = [NSData dataWithBytes:(void*)patternArray length:
           numberOfEntries];
14
15     ALog(@"** data: %@", data);
16
17     [_rfduino send:data];
18
19 }
```

Listing 5.12: Send a vibration pattern to the vibrating bracelet.

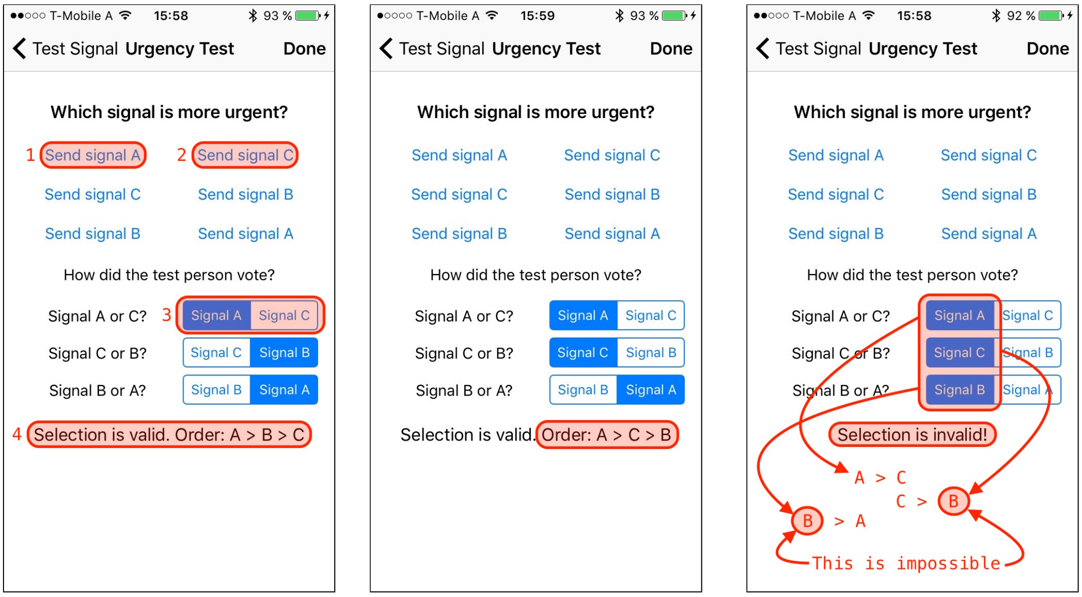
These are the basics of how receiving an Apple Push Notification, processing it, and sending it to the vibrating bracelet works. The full source code can be seen here [84].

User test specific implementation

As described in Section 7.2 *Recognizing Urgency Levels*, the test scenario consisted of a tester and a test person. The test person had to wear the vibrating bracelet and react to vibration signals according to a written questionnaire which can be seen in Chapter 9 *Appendices*. The tester was using the described iOS application to trigger certain vibration signals on the vibrating bracelet at specified times and to validate answers given by test persons. This section explains how the iOS application was designed to assist the tester with the task of user testing.

The iOS application has been used during each user test to trigger vibration signals on the vibrating bracelet, while a test person was wearing it. Different aspects of the user test had different screens in the iOS application and the screens correlated with the questionnaire in Chapter 9 *Appendices*.

Determining perceived urgency of vibration signals: On Page 106 (Page 2 of the questionnaire), the perceived urgency levels of three different vibration signals were



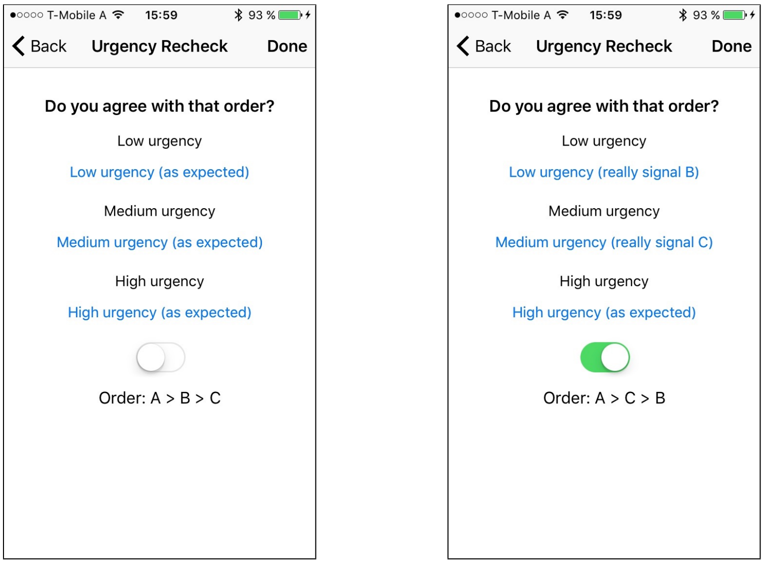
(a) Expected selection. (b) Unexpected selection. (c) Invalid selection.

Figure 5.13: Test screen to determine the perceived urgency of vibration signals.

tested. Note: The different patterns of those vibration signals will be described in 6.2.2 *Tested Vibration Signals*. Figure 5.13 shows the screen that correlates with the questions necessary to determine an order of urgency for the three vibration signals. Inspired by the experiments of Saket et al. [11] (see Section 7.2 *Recognizing Urgency Levels*), a pairwise comparison of all three vibration signals has been made and the test person had to rate one signal as more important for each comparison.

Figure 5.13 demonstrates the workflow for the tester during a test situation:

1. The tester tells the test person to wait for two vibration signals and be aware of how urgent each of those signals are perceived.
2. The tester first clicks on the `UIButton` "Send signal A" in the first row to trigger the first vibration signal and then on "Send signal C" to trigger the second vibration signal. These steps are indicated by the marked red areas "1" and "2" in Figure 5.13a.
3. The tester asks the test person whether the first or the second signal has been perceived as more urgent and offers to repeat the process if necessary.
4. The tester either repeats the two signals or clicks the `UISegmentedControl` [85] for "Signal A" if the first signal was perceived as more urgent, or "Signal C" if the second one was perceived as more urgent. The latter can be seen in Figure 5.13a, the position being marked by the red area "3".



(a) Expected selection. (b) Unexpected selection.

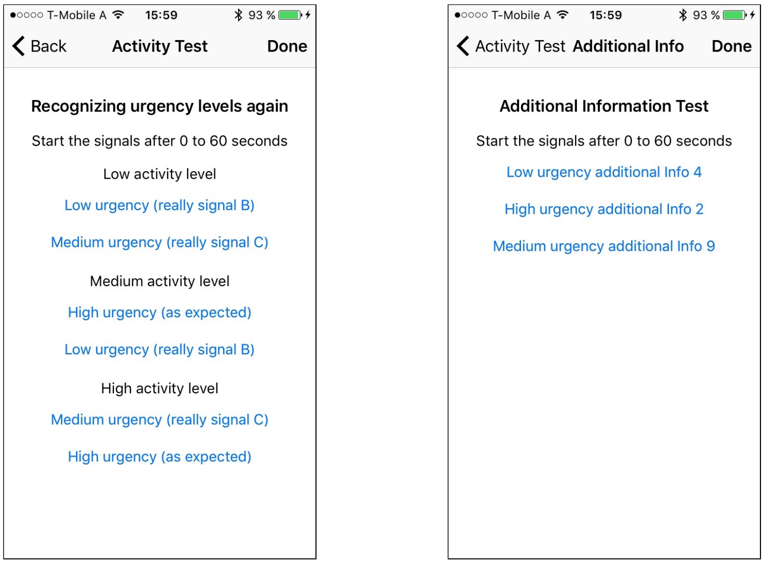
Figure 5.14: Test screen to verify the perceived urgency levels.

5. Points 2 to 5 are repeated for the second and third pairwise comparison.

6. At this point, the `UILabel` seen in Figure 5.13a marked area "4" displays two things: whether or not the selection is valid, and in case it is, the perceived order of urgency for the 3 vibration signals.

   Figure 5.13a (marked area "4") and Figure 5.13b (marked area) both show valid selections. Whereas the former shows the expected urgency ranking, the latter shows one possible unexpected ranking. In both cases, the tester can proceed to the next screen (see Figure 5.14). From that point on, the tester will always send urgency levels specific to the perceived urgency levels of the test person. However, in case the selection is invalid, the tester is not able to proceed to the next screen. An invalid selection can be seen in Figure 5.13c. As indicated by the arrows and text, the selected order of perceived urgency is not conclusive and thus impossible. In such a case, the tester has to start over with the pairwise comparison until a conclusive order is reached.

Verifying urgency levels: Figure 5.14 shows the screen to verify the perceived order of urgency levels. Here, the tester has to check whether or not the test person agrees with the determined order. The tester clicks on the buttons for "low urgency", "medium urgency", and "high urgency" in turn and verifies with the test person whether or not that order is correct. As seen in Figure 5.14a, the urgency levels match the expected order. Figure 5.14b however shows one possible unexpected order of urgency levels. The



(a) Testing urgency levels. (b) Testing additional information.

Figure 5.15: Testing recognizability of urgency levels and additional information.

expected order is always irrelevant for the test person. For the tester, however, it acts as information on which vibration signal the test person is supposed to identify.

As seen in Figure 5.14, the urgency order has to be confirmed by a `UISwitch` [86]. Only when the `UISwitch` is set to `on`, the next screen can be reached.

Activity levels and additional information: The next screen is shown in Figure 5.15a and corresponds to Pages 108 to 110 (Pages 4 to 6 of the questionnaire). This screen represents one of the key aspects of the whole user test: Determining whether or not test persons are able to identify vibration signals in different situations. As described in Section 6.1 *Hypotheses*, a lot of hypotheses revolve around the recognition of different urgency levels of vibration signals under varying circumstances. This screen (Figure 5.15a) uses the test user-specific mapping of urgency levels again. In this example, the test user mapped signal B as the lowest urgency and signal C as medium urgency which does not match the expected order.

The final screen can be seen in Figure 5.15b. This screen is used to test whether or not test persons are able to distinguish additional information after a vibration signal. On Page 111 (Page 7 in the questionnaire) the corresponding question can be seen.

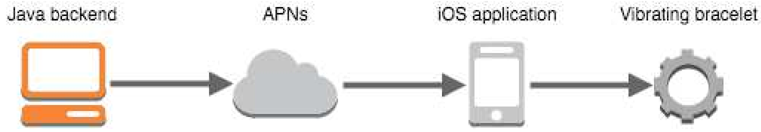


Figure 5.17: Communication flow.

5.7 Java Backend

For a vibrating bracelet to receive an encoded vibration signal, it needs to be connected to an iOS device. The bracelet then waits for the iOS application to send data (i.e., a vibration signal). One part of the iOS application has a very similar role to the bracelet: namely, the push notification handlers. They register to the APNs on the first startup and they are then able to receive push notifications from a provider (as outlined in "Provider"). This section describes how a provider can be implemented in Java. The Java application has been developed with a simple User Interface (UI) that enables a user to specify a custom vibration pattern to be sent to the vibrating bracelet.

The pattern to be sent consists of multiple lines of configurable values for vibration intensity and duration. If a user wanted to specify a simple on/off pattern for example, the first row would contain a high number less or equal to 255 for the intensity and a duration in milliseconds (1000 for example). The second row would contain a very low value for intensity and again a duration in milliseconds (see Figure 5.16). This pattern can then be chosen to be repeated a configurable number of times. Sending the specified pattern is done by clicking the "send" button. The UI has been made a very simple JSF application on purpose and is not supposed to be more than a simple testing interface. The main focus has always been the underlying implementation.

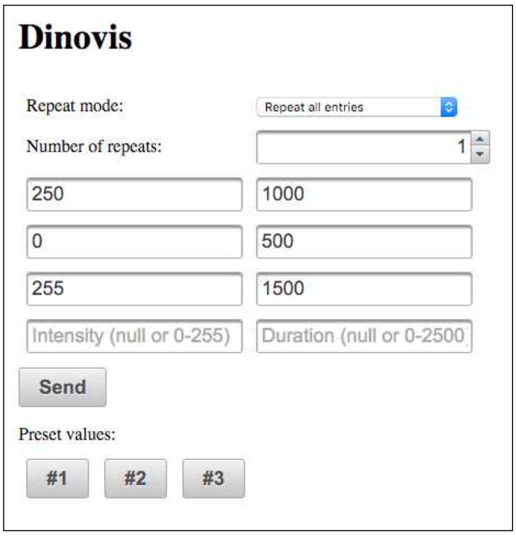


Figure 5.16: JavaServer Faces (JSF) frontend.

The purpose of this section is to prove that an external application is able to send push notifications to the vibrating bracelet. However, since the application is a prototype, a few shortcuts have been taken. The communication between Java application and APNs, as well as shortcuts that have been taken, will be described in detail. All communication-related issues will be described from the perspective of the Java backend. As highlighted in Figure 5.17, the Java backend is the first actor in the communication chain.

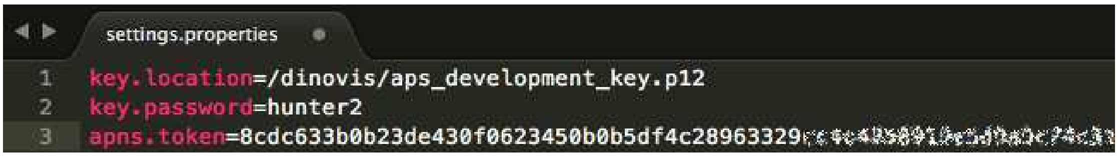


Figure 5.18: Properties file containing PKCS#12 file information and APNs token.

5.7.1 Backend to Bracelet Communication

The Java application does not directly communicate with the vibrating bracelet, nor the iOS application. As far as the Java backend (i.e., the provider; see 5.6.1 *Technology*, "Provider") is concerned, the only communication partner is the APNs. As described in Section 5.6.1, any application wanting to send data to a push notification enabled device, has to first know the device token of the corresponding device. The only way for a provider to know that token, is to request it from the iOS application.

```
- (void)application:(UIApplication *)application
    didRegisterForRemoteNotificationsWithDeviceToken:(NSData*)deviceToken
{
    NSLog(@"My token is: %@", deviceToken);
}
```

Listing 5.13: After successful registration for remote notifications.

As mentioned before, a few shortcuts have been taken and within the scope of the prototype, registering, managing, and storing tokens of different devices is not included. For this reason, the token was simply read from logging output of the `AppDelegate` class from the iOS application (see Section 5.6.2 *Push notification handling*), by a method called `application:didRegisterForRemoteNotificationsWithDeviceToken:`. This method is part of the aforementioned `UIApplicationDelegate` (see Listing 5.13). The resulting device token has then been hard-coded into a properties file of the Java backend (see Figure 5.18).

5.7.2 Technology and Implementation

The Java backend has been developed using JavaEE 7. For dependency management, Maven 3 has been used. The user interface has been created using JSF with PrimeFaces [87]. The application is deployed on a WildFly 8 application server. Communication to the APNs is realized with a library called "notnoop" [88] which makes it very easy to build notifications with custom payloads. This library is available under a 3-Clause BSD License [89].

Starting up the ApnsService: Before push notifications can be sent, a certificate has to be created and saved as a password protected PKCS#12 file. This certificate has to be added to the Apple development account as described in detail by Apple in [90].

The PKCS#12 file is then used to setup notnoop's `ApnsService`, as seen in Listing 5.14. The singleton pattern is utilized in a class called `APNManagerSingleton` to make sure that not more than one connection to the `ApnsService` is open at any given time. All interaction with the APNs, including sending push notifications are done by this class.

```
1  @Startup
2  @Singleton
3  public class APNManagerSingleton {
4
5     private ApnsService service;
6     private String token;
7
8     @PostConstruct
9     private void startup() {
10       service = APNS.newService().withCert(PropertiesHelper.getProperty("
            certificate.location"), PropertiesHelper.getProperty("certificate.
            password")).withSandboxDestination().build();
11       token = PropertiesHelper.getProperty("apns.token");
12    }
13
14    // more code
15 }
```

Listing 5.14: Initializing the ApnsService class within APNManagerSingleton. Note: This has been shortened substantially. See full source code at: [91]

Line 10 (Listing 5.14) shows how the `ApnsService` is initialized, using the PKCS#12 certificate and the corresponding password. Both certificate location and password are read via properties file (see Figure 5.18) with a simple properties reader class called `PropertiesHelper`.

Apple differentiates between development and production environments for APNs, where the development environment is referred to as "sandbox". `ApnsService` has to be initialized to be either one of those two by calling `ApnsServiceBuilder.withSandboxDestination()` or `ApnsServiceBuilder.withProductionDestination()`. The Java backend uses the former, since the iOS application is not in a production environment. Note: To use the production environment settings, it requires an iOS application to be published to the Apple App Store.

In Line 11 (Listing 5.14), the token gets read from the aforementioned properties file. This token is the unique identifier for one specific iOS device. As mentioned in Section 5.7.1 *Backend to Bracelet Communication*, only one token of a test device has been hard-coded into the application. This is one of the shortcuts that have been mentioned earlier.

```
1     /**
2      * Constructs a push notification with a defined payload and sends it.
3      *
4      * @param repeatMode value of the custom payload field "repeatMode"
5      * @param repeats value of the custom payload field "repeats"
6      * @param values values for the custom payload fields according to the
          given map
7      */
8     public void sendNotification(int repeatMode, int repeats, Map<String,
         String> values) {
9
10        logger.debug("sendNotification. Repeat mode: " + repeatMode + ",
             Repeats: "+repeats+", values: "+values);
11
12        String payload = APNS.newPayload().alertBody(getAlarmString()).
             customField("repeatMode", String.valueOf(repeatMode)).customField("
             repeats", String.valueOf(repeats)).customFields(values).build();
13        service.push(token, payload);
14
15        logger.debug("sendNotification done!");
16    }
```

Listing 5.15: Send a push notification within APNManagerSingleton.

Sending a push notification: A part of the aforementioned `APNManagerSingleton` is used to send push notifications. Listing 5.15 shows how the `sendNotification()` method takes all necessary information to send a push notification as parameters. This includes the `values` map which holds all custom fields for the notification payload. Those custom fields are the intensity/duration-pairs. As seen in Line 12 (Listing 5.15), notnoop's `PayloadBuilder` is able to easily add custom fields to a payload String. With the `PayloadBuilder.customFields(final Map<String, ?> values)` method, a whole map can be added at once to the payload. When building the payload String, JSON output is generated from with the given values. The result of such a JSON output has been shown in Listing 5.9, in Section 5.6.2 *Push notification handling*.

When sending a push notification, the `ApnsService` needs both a token and a payload, as seen in Line 13 (Listing 5.15). Calling the `push` method initializes the Secure Sockets Layer (SSL) handshake with the APNs and sends the notification.

That concludes the description of the relevant parts of the Java application. As described initially, a few shortcuts have been taken while developing the Java application, including the following:

- The absence of handling different device tokens to send notifications to more than one iOS device.
- Related to that: The device token being hard-coded into a properties file.
- The application running in development mode.
- No proper error handling in case anything connection related happens while starting the `ApnsService`, building a notification payload, or while sending a push notification.
- General polish, especially concerning the JSF application which is very rudimentary.

Those points should be addressed when extending this application or when building a similar provider application. Last but not least, for communication purposes to the APNs, it might be interesting to use "pushy" [92] instead of "notnoop". This library from engineers at Turo (formerly known as RelayRides) is available under the MIT License [93]. It provides excellent documentation and is actively being developed. The only downside is that it does not provide functionality to add a whole `Map` as payload.

The full source code of the Java application can be found on Bitbucket [94].

Part III

Evaluation

CHAPTER 6

Hypotheses and User Tests

Dinovis is supposed to help people with nursing responsibilities lead a carefree life, without having to worry about missing an emergency concerning their patients.

To achieve this goal, a vibrating bracelet has been developed (see 5.2 *Vibrating Bracelet*. This chapter will first focus on defining hypotheses about the vibrating bracelet: about perception of vibration, recognition of urgency in vibration signals, and encoding meaning into vibration signals. Afterwards the focus will be on defining user tests and surrounding conditions.

6.1 Hypotheses

This section will focus on formulating hypotheses that will be answered by the user tests. These hypotheses were formulated before the questionnaire for the user tests had been developed and will be evaluated in Chapter 8 *Analysis*.

1. **The wearer of the vibrating bracelet is able to feel vibration coming from the vibrating bracelet.**

   When a test user is wearing the vibrating bracelet on his or her arm, it should be easily recognizable for the wearer whenever a vibration signal is transmitted. “Wearing the bracelet” means that a wearer has direct skin-to-bracelet contact without any number of layers of fabric in-between.

   This is the most important hypothesis, as it is a requirement for the other hypotheses. None of the other hypotheses can turn out to be true if this one is not.

2. **Three different vibration signals can be recognized and distinguished easily.**

   This hypothesis assumes that it is possible for a test person to both recognize three different vibration signals, as well as being able to distinguish them.

   For this hypothesis to turn out to be correct, two things are needed:

   - For all three vibration signals, a test person has to be aware of the incoming vibration signal.
   - The test person is supposed to always clearly recognize a difference between different vibration signals.

3. **The vibration signals can be designed in a way that different test persons, without instructions, perceive them at the same level of urgency.**

   Since the vibration signals are designed according to studies (see 6.2.1 *Urgency*), it is assumed that a large percentage of test users should be able to perceive the three vibration signals as the same level of urgency. There are three vibration signals which shall be called "Signal A", "Signal B", and "Signal C" in this context. Those three vibration signals are designed to represent three levels of urgency: "high urgency", "medium urgency", and "low urgency."

   Note: Test persons will not get to know the naming of each signal (e.g., "Signal A"), as that could be recognized as an indicator of the expected response.

   For this hypothesis to be correct, most test persons should perceive each signal as the urgency levels they are designed to be. This means that Signal A should be perceived as high urgency, Signal B as medium urgency, and Signal C as low urgency.

4. **Once those three vibration signals are known to a test person, they can be recognized again.**

   After a person knows all three signals and has associated them with three different urgency levels, it is assumed that such a person will be able to name the urgency level of any of the three signals.

   To test this hypothesis, a test person is first presented with the three different signals. Upon agreeing on which signal is supposed to represent which urgency level, the test person will receive different vibration signals and will be asked to name the urgency level they supposedly received.

   A test will be done while minimizing the level of distraction for the test person. This means that the test will take place in a quiet environment, with the test person sitting and being prepared to receive a vibration signal.

   The hypothesis will be correct if most signals throughout different tests are recognized as the correct urgency level.

5. **Test persons are able to recognize three different signals under different circumstances (e.g., while doing something physically exhausting).**

   This hypothesis goes one step further than Hypothesis 4, as it is assumed that urgency levels can be recognized while doing physical activities.

   For testing purposes, three levels of activity shall be defined as follows:

   a) **Low activity level:** Having a sitting position and not doing a lot of movement. This entails activities like working on a computer, reading a paper, or having lunch.

   b) **Medium activity level:** Going somewhere while carrying a relatively light weight. This level is defined to simulate situations where hands are preoccupied with a different activity. Carrying a grocery bag would be an example for that activity level.

   c) **High activity level:** Extensive physical activity. Test persons should be able to pursue sportive activities, while still being able to recognize an incoming vibration signal.

   To prove this hypothesis right, test persons have to be able to recognize urgency levels of vibration signals, even at different levels of activity.

6. **The level of physical activity, while receiving a vibration signal, is a hindering factor in correctly identifying a known vibration signal.**

   It is assumed that a higher level of activity (as defined in Hypothesis 5) makes it harder for test persons to identify which urgency level they receive.

   The three activity levels are each expected to increase the difficulty for a test person to correctly identify an urgency level. As such, each level of increased activity is expected to either have the same number of correct answers, or less.

   This hypothesis fails, if a higher activity level produces better results (i.e., more correctly identified urgency levels).

7. **With a higher level of physical activity, test persons will be less aware of a vibration signal.**

   It is expected that high levels of activity (as defined in Hypothesis 5) increased the difficulty for test persons to feel an incoming vibration signal because of sensory overload.

   Test persons are still expected to recognize incoming vibrations, but the level of awareness is expected to be less for each consecutive level of activity.

   To evaluate this hypothesis, test persons will be asked how aware they are of an incoming vibration signal for each activity level. This hypothesis fails if results suggest that an increased level of activity leads to an increased level of awareness.

8. **Most test persons will be able to correctly identify vibration signals, even at highest levels of physical activity.**

   In this context, “most” shall mean that at least two-thirds of all answers are expected to be correctly identified urgency levels, even for the highest level of activity (as defined in Hypothesis 5).

   This also means that according to Hypothesis 6 all other activity levels are expected to have an equal or a higher ratio than two-thirds of correctly identified urgency levels.

9. **A simple way of transmitting additional information (where the number of vibrations has to be counted) will lead to a very high rate of correctly identified messages.**

   Transmission of additional information as described in Subsection 6.2.2, is expected to have very good results. Meaning that at least 80% of all answers are expected to be correct.

   It is important that test persons are able to see the urgency levels and the additional information as two different and independent part of a vibration message. For that reason, test persons will receive different urgency levels with a varying number for the additional information. Test persons will then be asked to report the number for the additional information they received.

10. **Up to nine different messages will be identifiable that way.**

    This is an addition to Hypothesis 9. It is assumed that any number of additional information can be determined by test persons with the same precision, when the number of additional information is anywhere between one and nine.

    For this hypothesis to prove correct, there should be no recognizable drop in correctly identified additional information, when the number gets higher.

6.2 User Tests

In about a dozen tests, test users will be handed the aforementioned bracelet and they will be asked to describe how they perceive different vibration notifications under different circumstances.

The vibration notifications used for these tests are developed according to research in Chapter 3 *Vibration*. Each user test has been developed with a corresponding hypothesis in mind and will be evaluated in Chapter 8 *Analysis*.

The target audience for this user test will be as follows:

Age:	20-65
Gender:	Mixed
Number of persons:	10
Background:	Persons with different background

- **Age:** The age range has been chosen to be wide because age is not considered to be a limiting factor for this study.
- **Gender:** A gender ratio of about 50% female and 50% male has been chosen.
- **Number of persons:** The chosen methodology leans towards qualitative research, where 10 persons are considered a good amount.
- **Background:** In order to avoid creating a device with a very narrow application area, an effort has been made to get test persons with different backgrounds and professions.

6.2.1 Vibration Pattern Structure

A vibration pattern is a combination of varying, successive vibration strengths that all last for a fixed amount of time.

For the user test to create meaningful results, the attributes of vibration patterns used in the tests have to be defined.

Vibration strength

As mentioned in Section 3.2.1 *Perceived Urgency of Vibrotactile Signals*, extremes are best to distinguish. The vibrating bracelet is able to receive a vibration strength value between 0 (off) and 255 (maximum vibration value), as described in Section 5.5.1 *Pattern Encoding*. However, considering that extreme values are easiest to distinguished, vibration patterns used for the user test will only include patterns that consist of full on (255) and full off (0 [1]) values.

[1]Note: Section 5.5.2 *Why intensity 100 instead of 0 for OFF?* explains why a full off is not really 0.

Vibration duration

In consideration of Section 6.2.1 *Vibration strength*, "vibration duration" is describing the temporal length of only two states:

Vibration: The duration of a continuous vibration (i.e., "on state").
Pause: The duration of a pause (i.e., "off state").

According to [35, 11], it is hard to distinguish a lot of different vibration durations. Since this user test focuses on the real-world application of a specifically developed vibrating bracelet (Dinovis), it will follow the example of previous studies [11] and there will only be two different durations for both states:

Short: This will be 200ms.
Long: This will be 600ms.

The great relative difference between those two values will help test persons to easily distinguish between long and short durations, for either vibration or pause.

Pattern structure

With vibration strength and vibration duration defined previously, a vibration pattern will be defined to consist of alternating states of vibration and pause. Meaning that "on state" will always be followed by "off state" and either of them might be of long or short duration independently and repeatedly.

Pattern complexity

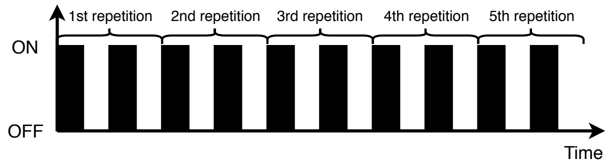
Studies have shown that it is not easy to distinguish long and complex vibration patterns [35, 11]. In fact, these studies suggest that not more than two pairs of vibration and pause pairs should be used. This means that a vibration pattern will consist of either one on/off pair or two on/off pairs.

The vibration pattern will then be repeated for a set amount of seconds, before it ends.

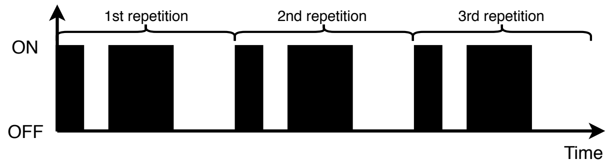
Examples:	Long on / long off	*(repeated for X seconds)*
	Short on / long off, long on / short off	*(repeated for X seconds)*

Urgency

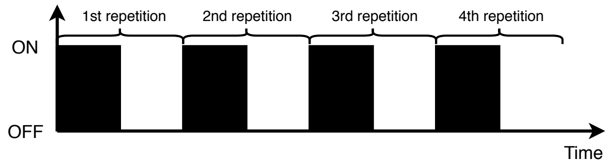
According to [11], shorter gaps and shorter vibrations are indicators for urgency. In this context, it will be important for test users to reliably be able to distinguish three different levels of urgency. Test users will not be given instructions on how they are supposed to distinguish urgency levels.



(a) High urgency signal.



(b) Medium urgency signal.



(c) Low urgency signal.

Figure 6.1: The three urgency levels used in the user tests.

6.2.2 Tested Vibration Signals

According to the presented information in 6.2.1 *Vibration Pattern Structure*, three different vibration patterns, each representing a different level of urgency, have been designed and used for the user tests.

Figure 6.1 shows a graphic visualization of the tested vibration patterns. Each vibration pattern consists of a signal and a pause. Both the signal and the pause vary between 200ms and 600ms, as described in 6.2.1 *Pattern complexity*.

Note: As seen in Figure 6.1a, one repetition marks two vibration intervals each. This has something to do with the implementation which only allows a maximum of 5 repetitions of a vibration pattern (see 5.5.1 *Pattern Encoding*: "Number of repetitions").

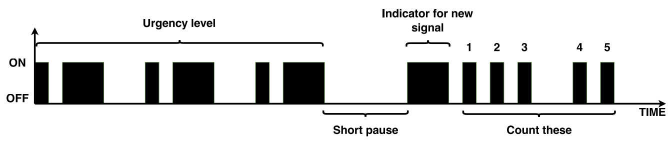


Figure 6.2: Vibration signal and additional information.

Additional information

Additional information will be transmitted after the regular vibration signal (i.e., after the urgency levels). To separate the additional information from the urgency level, a longer pause will be made after the transmission of the urgency level. Afterwards, there will be a long vibration to indicate the start of the additional information. This is followed by a number of one to nine short vibrations, where the number of vibrations indicates one out of nine possible meanings. See Figure 6.2 for illustration.

CHAPTER 7

Result Evaluation

In this chapter, the results of the user test (as seen in the Appendices) are evaluated. As described in detail in Section 6.2, ten test users were chosen with an equal distribution of female and male test persons. The test persons also varied in age and profession.

The following sections will summarize the results.

7.1 Test Users

Out of the ten test users, five were female and five were male. An effort has been made to have a relatively even distribution in age and a completely even distribution in gender for the test users.

The target age group was defined to be between 20 and 65 years old. In this broad age group, the average age would be 42.5 years. The test users come relatively close to that perfect average age, as the total average age was 40.9 years (see Figure 7.1) for all test users.

The background of the test users was very heterogeneous professions included (ordered by age): a midwife, two artists, an information scientist, two postgraduates, an architect, a screenplay writer, a housewife, and a retiree.

7.1.1 Time per Test

The average time for a test user to complete the test was about 30 minutes. Measuring the exact time has not been considered of great importance initially. Nevertheless, for half the tests an exact time measure was taken. Out of those five tests, the fastest test finished in 21 minutes, whereas the longest one took 42 minutes. For the remaining five tests, approximate times were taken right after the test.

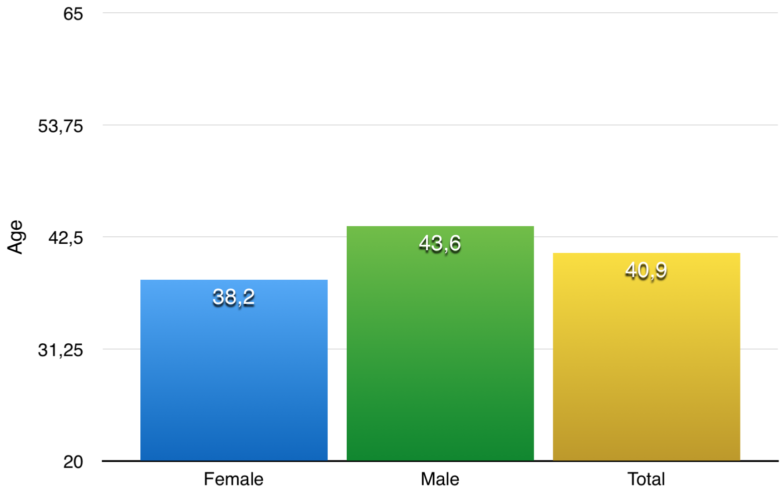


Figure 7.1: Average age of test users.

Taking only the exact times, the average time to complete a test was 32 minutes and 36 seconds. Including the approximate times, it comes down to an average of 28 minutes and 48 seconds. See Appendices for more information.

7.2 Recognizing Urgency Levels

The questionnaire was printed as seen in the Appendices. Test users were asked to write their answers on their own, in either English or German. All questions were explained to the test users before each corresponding test started.

The test persons were presented with three different vibration signals. As seen in the Questionnaire Appendices, questions 2.1 to 3.2 were used to determine a conclusive order of perceived urgency of those signals. Section 6.2.1 describes how the different vibration signals were designed to represent three different levels of urgency. These urgency levels were called "high urgency", "medium urgency", and "low urgency" and were expected to be recognized as such, when presented to a test person without instructions on how to distinguish the urgency levels. Test persons were asked to report which signals they perceived as more urgent on multiple pairwise comparisons.

Figure 7.2 shows the three different vibration signals on the x-axis and the perceived urgency color-coded on the y-axis. The signals shall be named "Signal A", "Signal B", and "Signal C" in this context, with Signal A expected to be perceived as the most urgent signal and Signal C expected to be perceived as the least urgent signal. As seen in Figure 7.2, most test persons perceived the urgency levels as expected: 70% perceived Signal A as the most urgent, 60% perceived Signal B to be of medium urgency and 50% perceived Signal C to be the least urgent one. According to the results, the most confusion was present with the supposed "low urgency" signal.

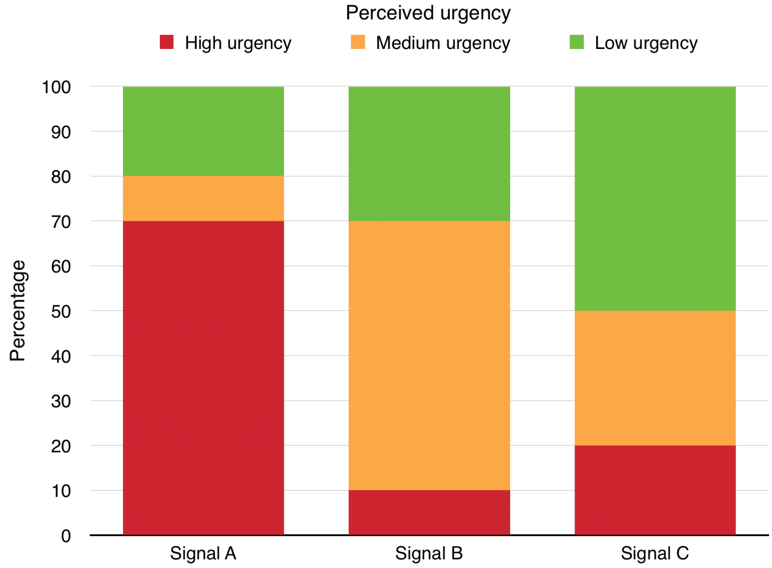


Figure 7.2: Perceived urgency levels of each signal.

7.3 Effect of Age

After the ordering of the urgency levels was settled for the test persons, it was tested whether they were able to recognize vibration signals again as one of the three urgency levels. The ordering of the urgency levels was according to the individual perception of urgency levels. Here an example: Question 4.1 would always send the signal that was perceived as "low urgency" to the corresponding test user, and therefore "low urgency" would always be the correct answer for any test user. As already seen in Figure 7.2, the signal perceived as one particular urgency level was not the same for all test persons.

In total, all test users were presented with six vibration signals and they were asked which urgency level they thought they received. When distinguishing between correct, undecided, and incorrect answers, it was most noticeable that the very oldest test persons had significantly more problems to correctly identify urgency levels (see Figure 7.3). The significance of the difference can best be seen by excluding those two outliers, while comparing the average number of correct answers: Without the two outliers, 95.83% of the remaining answers were correct, whereas only 16.67% of the answers from the outliers were correct. The effects of age will be further analyzed in Section 8.3.1 *The Effect of Age*.

7.4 Activity Levels

When testing the different activity levels, it became apparent that different test persons would interpret the same instructions differently. Especially in the highest activity level, where test persons were instructed to "start running in place" or do a similarly exhausting

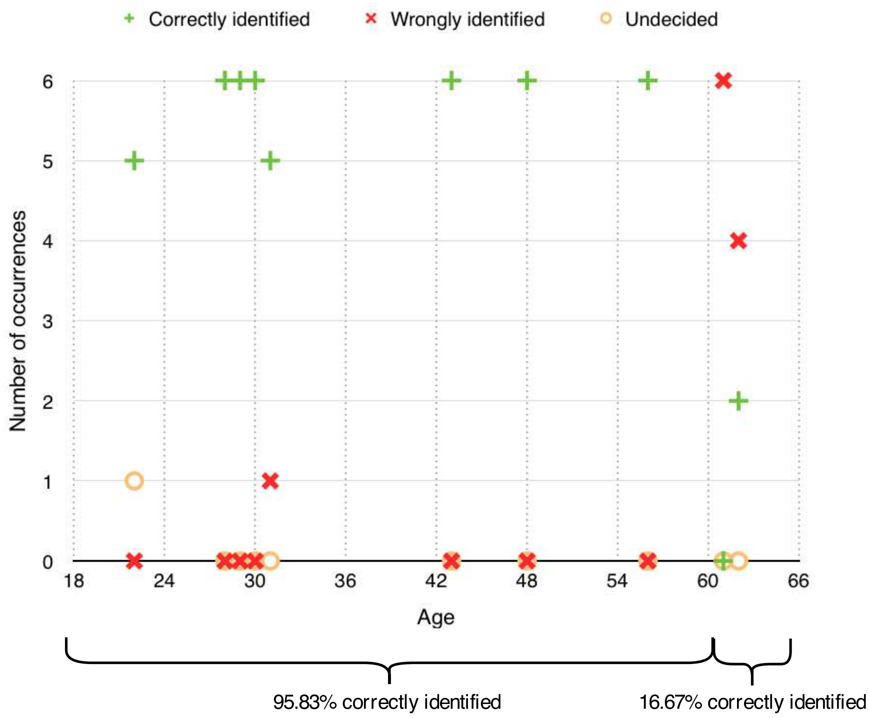


Figure 7.3: Correctly identified urgency levels per age.

activity, like jumping jacks. Here, different test persons would sometimes start the activity very enthusiastically and other times rather lazily. No direct correlation of performance and enthusiasms has been obvious though.

7.5 Vibration Intensity

Vibration intensity was tested by Question 8 of the Questionnaire (see Appendices). Test persons were asked to answer the question whether they perceived the vibration intensity in all tests as "too weak" or "too strong" in a 7-point Likert scale. Answering with a "4" meant that the vibration intensity was neither too weak, nor too strong. This would have been a perfect result.

Figure 7.4 shows that the vibration intensity was generally considered as being a bit too weak. The overall average was 3.2 (see "all" in Figure 7.4), with considerable differences between female and male test persons: Where female test persons had an average of 3.6, male test persons had an average of 2.8.

According to those numbers, the vibration intensity was almost perfect for female test persons, although it still has been perceived as a bit too weak. For male test persons however, the vibration intensity has clearly been perceived as too weak.

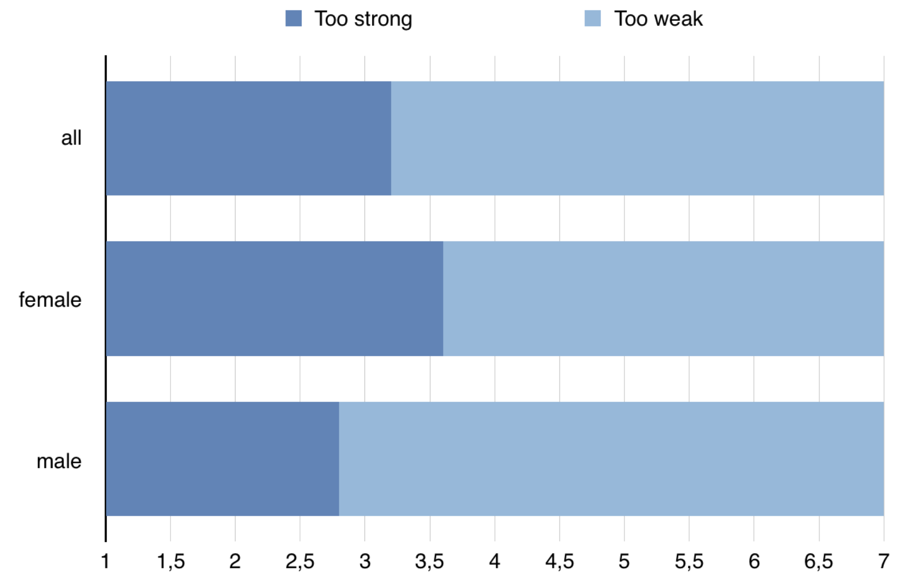


Figure 7.4: Perception of vibration intensity, including differences by gender.

7.6 Textual Questions

Questions 1 to 11 in the questionnaire consisted of single choice questions. The remaining four questions however were asked as free form questions. The following points will describe the summarized answers and the frequency they occurred. Similar answers (e.g., when different words for the same thing were used) were grouped together.

Not all questions have always been answered. The following sections will go into detail about the number of answers for each individual question.

7.6.1 Where to Use a Vibrating Bracelet?

An attempt has been made to group those answers into meaningful categories, as can be seen below.

Table 7.1 shows both the grouped keywords (Column "Grouping"), as well as the individual numbers of how often keywords have been mentioned on their own (Column "Count"). Column "Relevance" is a personal ranking of relevance for each keyword in the corresponding category. One such example for a silent environment would be that a ringing phone would be much more inappropriate in the theater than while eating. In this example the keyword "Theater" has a "High" relevance, whereas "Eating" only has "Medium" relevance for a silent environment. The last Column "Unique persons" is the number of test persons who mentioned at least one keyword of a corresponding group. This number does not necessarily add up with the sum from Column "Count", because a test person could have named several keywords from one group. In that case, the number of unique persons would still only go up by one.

Grouping	Keyword	Count	Relevance	Unique persons
Silent environments	Silent	3	Highest	
(i.e., sound inappropriate)	Meeting	3	High	
	Theater	2	High	5
	Cinema	1	High	
	Work	1	High	7
	Handy unfitting	2	Medium	
	Secret message	2	Medium	
	Eating	1	Medium	
	In company	1	Medium	
Loud environments	Loud	2	Highest	
(i.e., unable to hear sound)	Car	2	High	4
	Motorcycle	1	High	5
	Sport	2	Medium	
	Physical work	1	Medium	
Miscellaneous	Care taker	2	-	
	Call doctor	1	-	
	No free hands	1	-	6
	Shower	1	-	
	SOS	1	-	

Table 7.1: Fitting scenarios for the vibrating bracelet.

The original question here was (Question 12): “In which situations do you think vibration signals could be helpful?”

All test persons answered this question. The answers are ordered by frequency according to Table 7.1:

- **Mentioned seven times: In silent environments.**

  A silent environment is to be defined as an environment in which loud noises would not be appropriate.

  This point summarizes different keywords that were used to describe such environments.

  In total, seven out of ten test persons considered a vibrating bracelet to be useful in environments where silence is of importance. Three test persons explicitly wrote that it would be helpful in a silent environment, whereas the remaining four only mentioned situations that require a person to be silent. Here are a few situations that were mentioned: cinema, theater, or work.

  Figure 7.5 lists all keywords that were counted toward a “silent environment”, with different font sizes according to the relevance of each keyword. The same keywords

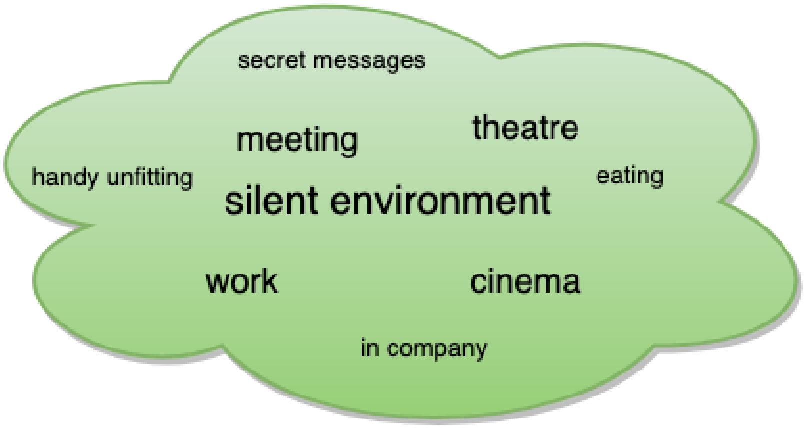


Figure 7.5: Words counted towards a "silent environment".

were used in the grouping in Table 7.1 which lists the numbers of occurrences of each keyword in detail.

- **Mentioned five times: In loud environments.**

  An environment in which sound would not be heard is to be defined as "loud environment".

  Just as with the previous point, this point summarizes different keywords that fit into the aforementioned "loud environment" definition.

  For this question, two test persons explicitly wrote about the usefulness in loud environments. Two additional test persons described situations that are in fact considered to be loud environments. They explicitly mentioned driving in a car (twice) or driving a motorcycle (once).

  See Figure 7.6 for more information of the words counted towards this category. The different font sizes represent the relevance of each keyword in this context. Furthermore, the size corresponds with the grouping in Table 7.1 which holds detailed information of the number of mentions of each keyword.

- **Mentioned two times and three times: Secret messages and meetings.**

  These answers are similar to the first one ("silent environment") but they focus more on being able to communicate without others noticing that communication took place.

  The usefulness of a vibrating bracelet in meetings has been mentioned three times. Only the keyword "silent" (i.e., useful in a silent environment) has been mentioned just as often.

  The thematically similar keyword "secret messages" has been mentioned twice in total.

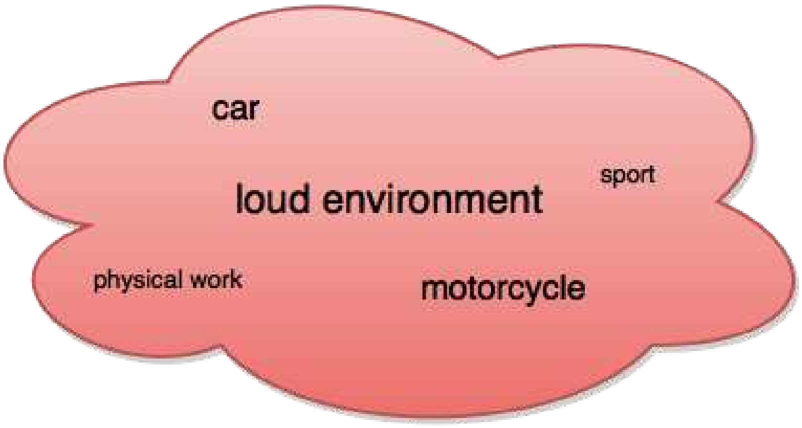


Figure 7.6: Words counted towards a “loud environment”.

- **Mentioned once each:**

  A number of different points were mentioned only once. These were as follows: Physical work, sport, in the shower, riding a bicycle, or having a nursing job.

  There was one additional mention that got into great detail: Calling a doctor (in a hospital setting) with different possible message meanings:

  - Ward round.
  - Examination.
  - Life threatening incident.
  - Other emergency.

  This detailed description came from a test person who works as a midwife.

7.6.2 What Could Be Improved?

This section is a summary of Question 13 to 15 from the questionnaire.

The original three questions were as follows:

Question 13: What would be preferred to vibration?

The original question here was: “Can you think of another way of notification that you would prefer to vibration?”

Four test persons answered this question with meaningful answers. Answers like “no” or “see above” were not counted. The answers are ordered by frequency:

1. Mentioned 3 times: Vibration plus blinking.
2. Mentioned 2 times: Additionally, an acoustic signal.
3. Mentioned once: A number display should be added additionally.
4. Mentioned once: Instead of a vibrating bracelet, just use a bell.

Question 14: What should be added to the vibrating bracelet?

The original question here was: "Are there features you would like to see added to the vibrating bracelet?"

Seven test persons answered this question with meaningful answers. The answers are ordered by frequency:

1. Mentioned 3 times: Adding blinking.
2. Mentioned 3 times: An additional "Repeat-Button".
3. Mentioned 2 times: Adding a "Cancel-Signal-Button".
4. Mentioned once: A numbers display.
5. Mentioned once: Replace the rubber band with a cotton band.
6. Mentioned once: Variable intensity for the vibration signal.

When comparing this question with the previous one, it becomes apparent that people mentioned some way of visual queue (i.e., adding blinking) in both questions. To get a better understanding of how many times a certain keyword has been mentioned in total, keywords will be grouped in 7.6.2 *Summary*.

Question 15: Suggestions?

The original question here was: "Are there any additional suggestions?"

Four test persons answered this question. These answers were mentioned once each:

- **Using the vibrating bracelet as an authentication device:**
  One test person with IT security background mentioned that a vibrating bracelet might be interesting for authentication purposes. It could be something like a rhythm-based two-factor authentication.
- **Somewhere less visible on the body:**
  A test person suggested that a bracelet might be too visible [for secret communication] and that other places on the body might be a good idea.

- **Make the bracelet more fashionable:**

  One suggestion was to make the vibrating bracelet more fashionable. If it was prettier, it would be seen as "jewelry", or even as "cool".

- **Individual signals:**

  Another suggestion was to be able to individualize vibration signals, so that not only the default signals are supported, but also custom signals.

- **Improve the material:**

  One test person suggested to do something about the material because it gets out of place when moving around a lot. This test person wanted the material to be more comfortable and suggested something like hunting calf. It should be a material that is soft and that prevents sweating.

Summary

Table 7.2 shows a summary of all suggested improvements. This summary groups answers from Question 13 to 15 from the questionnaire.

Grouping	Keyword	Count	Unique persons
Add output	LEDs	6	6
	Acoustic signal	2	
	Numbers display	2	
Add functionality	Repeat button	3	5
	Cancel button	2	
	Individual Signal	1	
	Variable intensity	1	
Modify bracelet	Better fitting	1	3
	Better material	1	
	Cotton band	1	
	Make it cool	1	
	Make it fashionable	1	
	Make it jewelry	1	
Miscellaneous	Authentication device	1	3
	Rhythm based authentication	1	
	Use a bell instead	1	
	Other place on body	1	

Table 7.2: Suggested improvements.

Extracting keywords independent of the question helps to visualize how frequent certain suggestions have been made by the test users. One such example would be the suggestion of additional blinking capability in Question 13 and 14. Another example would be the wish for a different material in Question 14 and 15. Grouping those answers makes it easier to see how often a specific idea has been suggested.

As seen in Table 7.2, more than half of the test users (six) suggested adding additional output. All of those test persons suggested adding LEDs, but two test users each also suggested adding an acoustic signal or a numbers display.

Half of the test users could imagine to add functionality, such as a repeat button, a cancel button, or individual vibration signals and vibration intensity.

Three test persons wanted to change the bracelet to be better fitting, of a different material, or more fashionable.

CHAPTER 8

Analysis

8.1 Analysis of the Results From User Tests

In Chapter 7 *Result Evaluation*, the results of the user tests have been presented without analysis. Here, the results will be interpreted and compared to the hypotheses (see 6.1 *Hypotheses*). 8.2 *Lessons Learned* will describe difficulties that had to be overcome and possible improvements. Finally, specific findings will be highlighted in 8.3 *Discussion* and conclusions will be drawn.

8.1.1 Evaluation of Hypotheses

In Section 6.1 *Hypotheses*, ten hypotheses were formulated. Those hypotheses were formulated before designing the user test and therefore also before performing the user test. This section will evaluate the validity of those hypotheses.

1. **Hypothesis:** "The wearer of the vibrating bracelet is able to feel vibration coming from the vibrating bracelet."

   Result: This hypothesis proofed to be correct. During the user test there was never a case where the test person was unable to feel an incoming vibration.

2. **Hypothesis:** "Three different vibration signals can be recognized and distinguished easily."

   Result: Correct.

3. **Hypothesis:** "The vibration signals can be designed in a way that different test persons, without instructions, perceive them at the same level of urgency."

   Result: This was mainly true. As described in Section 7.2 *Recognizing Urgency Levels*, most test persons perceived urgency levels as expected. Overall, 70%

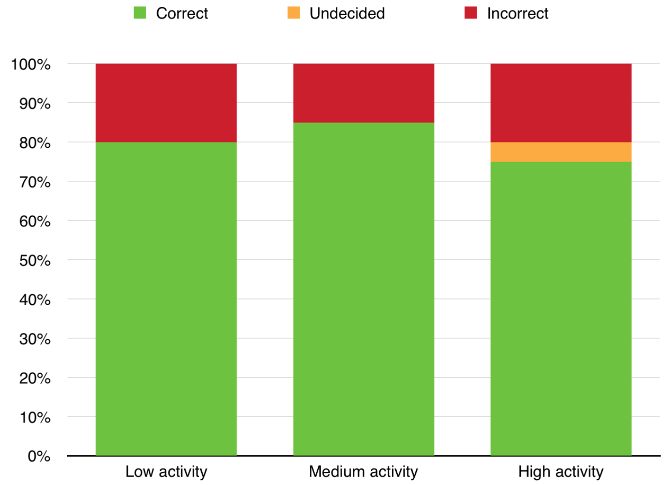


Figure 8.1: Recognition of urgency levels in correlation with physical activity.

identified the most urgent signal as expected, whereas 60% and 50% identified the signals with medium urgency and low urgency as predicted.

4. **Hypothesis:** Once those three vibration signals are known to a test person, they can be recognized again.

   Result: This was very much true. There was a significant exception concerning the oldest age group however. Details can be found in Section 8.3.1 *The Effect of Age*.

5. **Hypothesis:** "Test persons are able to recognize three different signals under different circumstances (e.g., while doing something physically exhausting)."

   Result: Only insignificant changes in correctly identified vibration signals could be associated with different activity levels. Figure 8.1 shows the correctly identified urgency levels in correlation with physical activity.

   Overall, the correctly identified urgency levels are lowest for the highest activity level (75%) and highest for medium activity levels (85%). As described in Section 8.3.1 *The Effect of Age*, age group D was mainly responsible for incorrect results. Omitting their results still produces insignificant differences.

6. **Hypothesis:** "The level of physical activity, while receiving a vibration signal, is a hindering factor in correctly identifying a known vibration signal."

   Result: As pointed out in Item 5, only insignificant differences were recorded. It has to be pointed out however that the highest activity level still had the worst recognition levels for urgency levels.

7. **Hypothesis:** “With a higher level of physical activity, test persons will be less aware of a vibration signal.”

   Result: On a 5-point Likert scale, test persons were asked to rate how aware they were of incoming vibration signals for each activity level. This resulted in a number between 1 and 5, with 1 being the worst outcome (“not at all aware [of the vibration signal]”) and 5 being the best outcome (“extremely aware [of the vibration signal]”). The lowest activity level had an average awareness of 4.1. Both the medium and high activity level had considerably less average awareness with 3.35 and 3.3 out of 5.

8. **Hypothesis:** “Most test persons will be able to correctly identify vibration signals, even at highest levels of physical activity.”

   Result: This proofed to be correct. As described in Item 5, 75% were able to correctly identify urgency levels even while being exposed to highest physical activity.

9. **Hypothesis:** “A simple way of transmitting additional information (where the number of vibrations has to be counted) will lead to a very high rate of correctly identified messages.”

   Result: Test results showed a 100% success rate.

10. **Hypothesis:** “Up to nine different messages will be identifiable that way.”

    Result: This hypothesis proofed to be correct as well, with a 100% success rate.

8.2 Lessons Learned

This section describes difficulties that had to be overcome to finish certain parts of this thesis. Specifically, after finishing the questionnaire, there were some interesting insights:

8.2.1 User Test

There were a few issues with the user test that should be improved in a future iteration:

1. During the user test, the users seemed a bit overwhelmed by the number tasks they were required to do. Those tasks included:

   a) Bracelet interaction according to the test scenario described in the Questionnaire (see Appendices).

   b) Describing how and when they perceived vibration, while being required to perform tasks associated with different levels of activity (see 7.4 *Activity Levels* and Hypothesis 5).

c) Answering questions from the Questionnaire (see Appendices) in written form. Note: Test persons sometimes had to move back and forth between the spot where they would perform the required physical activities and the spot where they would fill out the Questionnaire.

Since the test persons had all those tasks to do, there were times where the test instructor had to wait for the test persons to finish a task.

Conclusion: In hindsight, it would have been a good idea if the test instructor had written down the answers for the test users. First of all, this would have taken off Item 1c for the test users, meaning one less task for them to do. An additional benefit could have been a reduction of time per test completion on average, as the work would have been more equally distributed between test user and instructor.

2. The open questions without limitations made it hard to categorize similar responses (see 7.6 *Textual Questions* and specifically Table 7.1). Test users used different words or descriptions for similar problems or suggestions. For instance, 7 out of 10 test persons thought that a vibrating bracelet would be useful in a silent environment, i.e., in situations where loud notification cues would be inappropriate.

   However, only 3 test persons wrote something along the lines of "in a silent environment", whereas the others mentioned situations like:

   a) Being in a meeting
   b) Watching a film at the cinema
   c) Enjoying a play at the theater
   d) Sending a secret message

   Those situations imply that loud notification cues would be inappropriate, even though test persons did not explicitly mention it. In regard of appropriateness of loud notification cues, those situation are considered to be the same as "in a silent environment" (see Section 7.6.1 *Where to Use a Vibrating Bracelet?*).

   Conclusion: It is important to record every scenario a test person describes. However, to efficiently group similar answers afterwards, it would make sense to have more of a dialog with the test persons and guide their answers towards categories. It would be helpful to let test persons talk and the instructor take notes. With clarifying questions from the instructor, test persons might even be more inclined to express their thoughts more thoroughly.

3. Most test persons preferred to get the questions of the questionnaire explained to them, rather than reading them.

   Two questions in particular required additional verbal explanation:

a) Questions 3, 3.1 and 3.2 of the Questionnaire (see Appendices) needed additional explanation in almost all cases. About half of the test persons seemed confused at first, whether they should try to rate urgencies again or if they should try to recognize the urgency levels according to their previous rating (the latter would be correct).

b) Questions regarding additional information (Question 7, 7.1 and 7.2, see Appendices) needed additional verbal explanation. The visualization of the vibration signal helped a lot (Figure 7.1 of the Questionnaire, see Appendices).

Conclusion: It proved to be very efficient to verbally explain questions to the test persons. Verbally explaining questions had the added benefit that the test instructor could easily recognize whether or not a test person understood a specific question correctly.

However, it could be helpful to have an extended "script" prepared for verbal explanations.

4. The user test had two critical points, as illustrated in Figure 8.2:

a) First critical point: The user test required a valid order of urgency levels of the three vibration signals. In theory it could have happened that the pairwise comparison resulted in an invalid order. In that case, Question 2 would have been repeated.

Fortunately, this never happened in all user tests.

b) Second critical point: Question 3 determined whether or not test user agreed the resulting order of urgency levels. If this was not the case, the plan would have been to repeat Question 2 and Question 3. If that would have failed, the test would have been aborted.

As pointed out in Point 3a, Question 3 of the Questionnaire (see Appendices) often required additional explanation.

In one case, the test person thought that the vibration signals should be prioritized again, instead of verifying them. That test person did not agree with the order at first, but asked to get the verification repeated. After repeating verification that test person agreed with the order and the test could be proceeded.

Conclusion: It would have been preferred if there were no critical points in the Questionnaire. However, there seemed to be no reasonable way to avoid them:

a) The pairwise comparison of vibration signals in Question 2 served the purpose of verifying the levels of urgency described by Saket et al [11].

b) The verification of urgency levels was needed to name the three levels of urgencies. After the test person agreed with the order of urgency levels, the vibration signals would be referred to as: "low urgency", "medium urgency",

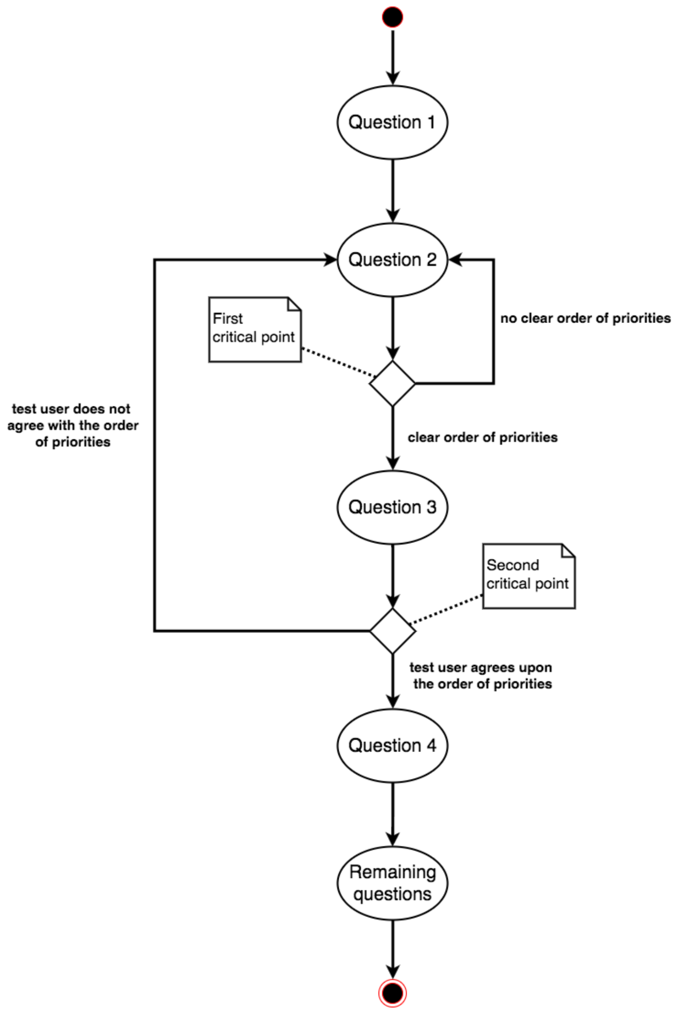


Figure 8.2: Critical points in the Questionnaire (see Appendices).

and “high urgency”. The naming of each vibration signal was adjusted to the individual perception of each test person.

8.2.2 Bracelet

It has to be pointed out that the bracelet is a prototype and was never designed to be a finished product within the context of this thesis. However, there were a number of valuable lessons to be learned while developing and testing the vibrating bracelet.

Vibration intensity: As seen in 7.5 *Vibration Intensity*, vibration intensity was generally perceived as being too weak. While female test users perceived vibration intensity only as a little bit too weak, male test users perceived it as significantly too weak.

In a future development, the vibration intensity should be made stronger. Ideally, there should be a way to regulate the vibration intensity (as suggested by a test person, see 7.6.2 *Question 14: What should be added to the vibrating bracelet?*).

Ways to increase vibration intensity:

1. The vibration motor could be replaced by a stronger one. With the given hardware limitations (maximum of 3V, very small measurements), there were not many choices of vibration motors available to buy. In fact, the online shop where the vibration motor has been ordered, offered only one motor fitting the requirements (see 5.3 *Building a Bracelet*).
2. With the bracelet being made of silicone, it absorbed part of the vibration intensity. Even though the vibration motor was positioned to be as close as possible to the wrist, there still was a gap between skin and vibration motor.

   This issue could be solved in two ways:

   a) Find a way to efficiently position the vibration motor to be in touch with the skin of the wearer.
   b) Use a different material for the bracelet that absorbs less vibration intensity. Most bracelets with vibration capabilities have a much sturdier case, allowing for better transmission of vibration.

Note: The initial vibration intensity has been increased by not completely stopping the vibration motor for short vibration gaps, as described in 5.5.2 *Why intensity 100 instead of 0 for OFF?*. The results presented here already include this particular improvement.

Further improvements to the bracelet: For future development, there are a number of improvements that would be interesting to implement. Some of them have been mentioned by test persons. The possible improvements mentioned by test persons have been evaluated in Section 7.6.2 *What Could Be Improved?*.

Here is a list of possible improvements, partially composed of suggestions by test users:

1. **Power switch:** As mentioned in Section 5.3 *Building a Bracelet*, a power switch could be added to the current prototype bracelet. This would allow for the bracelet to be powered off without removing the battery.
2. **Repeat signal button:** The vibration signals are by design repeated a few times (three or four times respectively, see Section 5.5.1 *Pattern Encoding*). However, after those repetitions, the test user has no way to repeat the signal again.
3. **Stop signal button:** There is currently no way to stop an incoming signal. There might be cases, where stopping a signal would be convenient.

4. **Different wristband material:** A different wristband material could serve two purposes:

   a) As pointed out in 8.2.2 *Ways to increase vibration intensity:*, the vibration intensity was reduced by the material. A sturdier material would help increase the vibration intensity.

   b) Some test persons did not like the material of the silicone wristband. One proposed material was a cotton band.

5. **Adding different notification cues:** Adding blinking, a display, or an acoustic signal has been proposed by test persons. This would of course change the classification of "subtle" and "private" as introduced by Hansson et al. [12] and explained in Section 2.2 *Avoiding Negative Implications of Notifications - Is It Possible?*.

6. **Customizable vibration intensity:** Making the vibration intensity customizable individually would make it much easier to find a convenient setting for all users. As described in Section 7.5 *Vibration Intensity*, female and male test persons perceived the vibration strength differently. According to the presented numbers, it seems unlikely that there would be a perfectly convenient setting for both female and male users.

8.3 Discussion

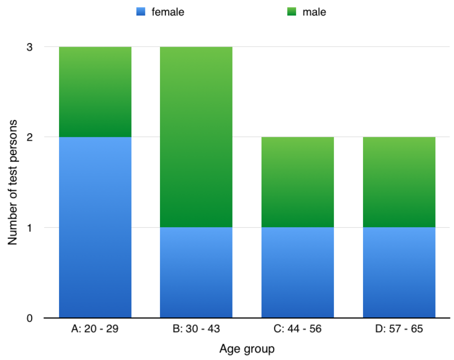
This section will highlight and reiterate findings both from the user test as well as the literature review. Those findings will be brought in context with the development of Dinovis. Finally, conclusions will be drawn and future work will be mentioned.

8.3.1 The Effect of Age

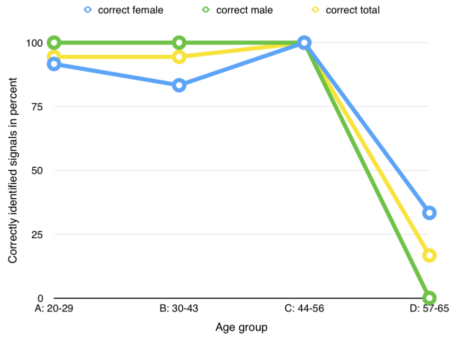
As described in Section 7.3 *Effect of Age*, there was a very significant difference in the number of correctly identified vibration patterns between the oldest test persons and the rest of the test persons.

The overall effect can best be seen when ignoring activity levels, while comparing the results of different age groups. For that purpose, the test persons have been split into four age groups (see Figure 8.3a). As pointed out in Section 7.1, the average test user was 40.9 years of age. To spread out the results and the test persons relatively evenly, the test persons have been split in four age groups: Group A (ages 20 to 29), Group B (ages 30 to 43), Group C (ages 44 to 56), and Group D (ages 57 to 65).

Figure 8.3b shows the significant drop in correct answers in Group D. While all age groups from A to C never had less than 94.44% correct answers in total, Group D only had 16.67% correct answers. Even though this result is very significant, it would be most interesting to see a more thorough study on the effect of age in combination with vibration signals.



(a) Distribution of test persons regarding age and gender.



(b) Percentage of correct answers per age group and gender.

Figure 8.3: Correlation of age and correct answers.

8.3.2 Information Overload

One primary intent of this thesis was to propose ways to lessen the negative impacts of information caused by notifications. As described in Chapter 2 *Notifications*, there are a number of negative effects notifications can have on us. This includes ADHD-like symptoms [1], attention overload [3, 12], reduced psychological well-being [1], and constant high alertness of notifications, even in silent modes [2].

The results from those papers suggest the following:

1. Intrusive notification cues can cause attention overload [3, 12]. For instance, such notification cues would be auditory cues that demand immediate attention.

2. Interruption results in a number of negative consequences [1]. Kushlev et al. proved that maximizing notification cues increases interruption which in turn increases negative consequences (see Section Subjectively Measuring Effects of Notifications for more information).

3. Only silencing phones is not enough for users to not pay attention to their phones. As pointed out by Chang et al. [2], more than half of their test persons would react to a notification within 6 minutes even in silent mode.

4. Being afraid to miss important information has been speculated [1] and identified [3] to be a reason for users to check their mobile devices regardless of ringer mode.

With the negative consequences connected to notification overload, it seems very important to work on solutions.

8.3.3 Avoiding Negative Effects of Notifications with a Vibrating Bracelet

The vibrating bracelet developed within the context of this thesis shows a possible way to deal with the presented issues.

A subtle way of notification: Hansson et al. described public and intrusive notification cues as problematic: "Attention overload concerns not only the owner or holder of a mobile device, but also other people nearby" [12].

To deal with attention overload, Hansson et al. suggested subtle notification cues. For a different reason, they suggested to also make notification cues public: They wanted to make receiving notification cues understandable for people nearby (see Section 2.2 *Avoiding Negative Implications of Notifications - Is It Possible?* for further information).

This part however is less important in the context of this thesis and could even be described as counterproductive: The developed bracelet has many possible use cases where privacy is of importance. Those use cases include being notified of a personal emergency at any time. This means being reachable in a meeting, while watching a movie, or while being in a silent or loud environment.

Avoiding interruption: As pointed out by Kushlev et al. [1], interruption has negative consequences. Interruption can be reduced by having the notification device in silent mode and out of sight. Kushlev et al. suspect that self-interruption is a big factor and assume that it happens out of fear to miss an important notification. This form of interruption even happens in silent mode and without the notification device in sight. The results of Chang et al. [2] show that users usually react to notifications within minutes, even in silent mode. Those results further suggest that self-interruption is very common.

A vibrating bracelet that only notifies the user in very urgent cases could potentially lessen the problem of self-interruption. The regular notification device could be in silent mode and out of sight and the bracelet user would still be notified in urgent cases.

Due to the design of the bracelet, it is open to receive custom vibration signals through a Java backend (see Section 5.7 *Java Backend*).

Classifications of which messages exactly should be transmitted to the bracelet will not be answered, as it has not been the context of this thesis.

Reasons for using a bracelet: Hansson et al. [3] as well as William et al. [13] had very positive reactions to their respective bracelet development (see Section 2.2 *Avoiding Negative Implications of Notifications - Is It Possible?* for more details). Both studies concluded that designs involving bracelets were very well received. Those were subjective results from test persons.

Machida et al. [14] measured vibration perception of various body parts. They came to the conclusion that the wrist is a very good choice when it comes to perception of vibration (see Section 3.1 *Physical Perception of Vibratory Signals* for more information).

Conclusion and future work: The results from this thesis verify findings from previous papers, as pointed out in 8.3 *Discussion*. Furthermore, the user test showed that a vibrating bracelet is perceived well by test persons. Information can be reliably transmitted to test persons via vibration signal.

Future work should include building a sturdier prototype with a stronger vibration motor. It would be very interesting to test perception of vibration more extensively with a larger number of an older demographic.

An unexpected finding was the difference in perception of vibration intensity between genders. This has not been mentioned in the referenced literature and might be of real interest for further research.

Thank you for reading this master thesis! In case this thesis gets picked up by another researcher: Please feel free to contact me with any questions, raw data sources, evaluation sources, or LaTeXsources of the Questionnaire at: ludwig.werzowa@gmail.com

Part IV

Appendix

CHAPTER 9

Appendices

9.1 Questionnaire

This is the questionnaire that has been used to conduct the user tests. Slight modifications, such as page scaling or removing original page numbers, have been made for the appendix to make the questionnaire fit better.

Each question has multiple possible answers, from which one has to be chosen. Additionally, there is room for optional comments.
Please answer the questions to the best of your knowledge. Thank you.

Personal information.

Gender: Female ☐ Male ☐

Age: ________

Preparation for the questionnaire:

- Make sure that the bracelet fits snugly.
- *For all the tests please immediately report whenever you feel a vibration signal.*

1 How aware were you of the vibration signal?

Not at all aware	Slightly aware	Moderately aware	Very aware	Extremely aware
☐	☐	☐	☐	☐

Optional comment: ....

2 Urgency levels

For the next questions, you will be presented with two vibration signals each.
Please rate on a scale which signal you perceive as more urgent.
In case you are unsure, please feel free to ask for a repetition.

2.1 Did you perceive the first or the second signal as more urgent?

	1	2	3	4	5	6	
Clearly the first signal							Clearly the second signal

Optional comment: ....

2.2 Did you perceive the first or the second signal as more urgent?

	1	2	3	4	5	6	
Clearly the first signal							Clearly the second signal

Optional comment: ....

2.3 Did you perceive the first or the second signal as more urgent?

	1	2	3	4	5	6	
Clearly the first signal							Clearly the second signal

Optional comment: ....

3 Verification of urgency levels

With the pairwise comparison of the previous test, three different signals got assigned to three urgency levels: low urgency, medium urgency and high urgency.
To verify those levels, you will now receive three signals in the following order:

1. Low urgency.
2. Medium urgency.
3. High urgency.

3.1 Do you agree with the ordering of the urgency levels?

Yes . . . . ☐
No . . . . ☐
Undecided . . . . ☐ ↦ *Please elaborate below:*

Optional comment: . . . .

3.2 Do you think it is likely that you will be able to recognize the three urgency levels (according to your test) again?

Not at all likely	Slightly likely	Moderately likely	Very likely	Completely likely
☐	☐	☐	☐	☐

Optional comment: . . . .

The next questions are about recognizing the different urgency levels again. You will be asked to simulate different circumstances. Again, please immediately report whenever you feel a vibration.

4 Low activity level

Please sit comfortably. You will receive a vibration signal within a minute after you are ready. Please immediately report when you notice it.

4.1 Which urgency level did you receive?

Highest urgency . . . ☐
Medium urgency . . . ☐
Lowest urgency . . . . ☐
Undecided . . . . ☐→ *Please elaborate below:*

Optional comment: . . . .

Please continue as before and wait for a second signal.

4.2 Which urgency level did you receive?

Highest urgency . . . ☐
Medium urgency . . . ☐
Lowest urgency . . . . ☐
Undecided . . . . ☐→ *Please elaborate below:*

Optional comment: . . . .

4.3 How aware were you of the vibration signals?

Not at all aware	Slightly aware	Moderately aware	Very aware	Extremely aware
☐	☐	☐	☐	☐

Optional comment: . . . .

5 Medium activity level

> Please stand up, take a shopping bag and walk around.
> You will receive a vibration signal within a minute after you are ready.
> Please immediately report when you notice it.

5.1 Which urgency level did you receive?

Highest urgency . . . ☐
Medium urgency . . . ☐
Lowest urgency . . . . ☐
Undecided . . . . ☐↦ *Please elaborate below:*

Optional comment: . . . .

> Please continue as before and wait for a second signal.

5.2 Which urgency level did you receive?

Highest urgency . . . ☐
Medium urgency . . . ☐
Lowest urgency . . . . ☐
Undecided . . . . ☐↦ *Please elaborate below:*

Optional comment: . . . .

5.3 How aware were you of the vibration signals?

Not at all aware	Slightly aware	Moderately aware	Very aware	Extremely aware
☐	☐	☐	☐	☐

Optional comment: . . . .

6 High activity level

Please start running in place. You will receive a vibration signal within a minute after you are ready. Please immediately report when you notice it.

6.1 Which urgency level did you receive?

Highest urgency . . . ☐
Medium urgency . . . ☐
Lowest urgency . . . . ☐
Undecided . . . . ☐ ↦ *Please elaborate below:*

Optional comment: . . . .

Please continue as before and wait for a second signal.

6.2 Which urgency level did you receive?

Highest urgency . . . ☐
Medium urgency . . . ☐
Lowest urgency . . . . ☐
Undecided . . . . ☐ ↦ *Please elaborate below:*

Optional comment: . . . .

6.3 How aware were you of the vibration signals?

Not at all aware	Slightly aware	Moderately aware	Very aware	Extremely aware
☐	☐	☐	☐	☐

Optional comment: . . . .

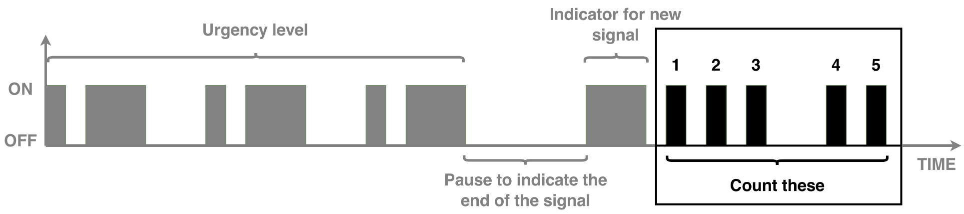


Figure **7.1:** Vibration signal and additional information

7 Additional information

The next test will determine how easy additional information may be transmitted.
For that purpose, a vibration signal will be followed by a pause, a long vibration interval and then by a number of short vibrations (in pairs of three).
Please report the number of vibrations you received (see figure **7.1**).

7.1 How many short vibrations could you feel?

The first time: ________
The second time: ________
The third time: ________

Optional comment: ....

7.2 Was it hard to know how many vibrations you received?

	1	2	3	4	5	6	7	
It was very hard								It was very easy

Optional comment: ....

General questions and suggestions.

8 How would you describe the **vibration intensity** in all tests?

	1	2	3	4	5	6	7	
Too weak								Too strong
Very uncomfortable								Very comfortable
Very hard to notice								Very easy to notice

Optional comment: ....

9 Is it easy to distinguish different **urgency levels**?

Extremely easy .... ☐
Very easy .... ☐
Moderately easy ... ☐
Slightly easy .... ☐
Not easy at all ..... ☐→ *Please elaborate below:*

Optional comment: ....

10 Is it easy to distinguish different **additional information** levels?

Extremely easy .... ☐
Very easy .... ☐
Moderately easy ... ☐
Slightly easy .... ☐
Not easy at all ..... ☐→ *Please elaborate below:*

Optional comment: ....

11 Do you think vibration is a good way to transmit simple information?

Extremely good.... ☐
Very good .... ☐
Moderately good... ☐
Slightly good ...... ☐
Not good at all .... ☐→ *Please elaborate below:*

Optional comment: ....

12 In which situations do you think vibration signals could be helpful?

. . . .

. . . .

. . . .

. . . .

13 Can you think of another way of notification that you would prefer to vibration?

. . . .

. . . .

. . . .

. . . .

14 Are there features you would like to see added to the vibrating bracelet?

. . . .

. . . .

. . . .

. . . .

15 Are there any additional suggestions?

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Thank you very much for your time!

9.2 User Test Results

Those are the raw data results of questions 1 to 11 from the questionnaire. Column "Expected or optimal" has been added to indicate the expected or optimal result. Example for an "expected result": A test person perceives the urgency level of a vibration signal as initially assumed. Example for an "optimal result": A test person is "extremely aware" of a vibration signal, rather than "not at all aware."

	1	2	3	4	5	6	7	8	9	10	Expected or optimal
Age	56	30	22	28	61	62	28	31	43	48	
Gender	m	m	f	f	m	f	m	f	m	f	
Time	±20	28	35	42	±30	±20	37	21	±30	±25	
Question 1	5	4	5	4	5	5	5	4	3	4	5
Highest	A	C	A	B	C	A	A	A	A	A	A
Mid	B	A	B	C	B	C	B	B	C	B	B
Lowest	C	B	C	A	A	B	C	C	B	C	C
Question 2.1	3	6	1	4	5	2	1	1	1	1	1
Question 2.2	5	1	6	5	3	2	6	6	2	5	6
Question 2.3	4	5	6	2	3	5	5	6	4	5	6
Question 3.1	y	y	y	y	y	y	y	y	u	y	y
Question 3.2	4	5	4	5	4	3	4	4	1	4	5
Question 4.1	L	L	L	L	M	M	L	L	L	L	L
Question 4.2	M	M	M	M	H	H	M	M	M	M	M
Question 4.3	4	5	5	4	5	2	5	4	3	4	5
Question 5.1	H	H	H	H	L	H	H	H	H	H	H
Question 5.2	L	L	L	L	H	M	L	L	L	L	L
Question 5.3	3	4	5	2,5	4	2	3	3	3	4	5
Question 6.1	M	M	M	M	L	L	M	L	M	M	M
Question 6.2	H	H	U (prob: H)	H	M	H	H	H	H	H	H
Question 6.3	3	3	3	3	4	4	3	3	3	4	5
Question 7.1a	4	4	4	4	4	4	4	4	4	4	4
Question 7.1b	2	2	2	2	2	2	2	2	2	2	2
Question 7.1c	9	9	9	9	9	9	9	9	9	9	9
Question 7.2	6	6	6	6	7	7	6	3	6	7	7
Question 8a	2	3	3	3	3	4	3	4	3	4	4
Question 8b	6	6	6	4	6	4	6	6	1	6	7
Question 8c	5	5	7	4	6	7	5	6	6	6	7
Question 9	3	2	1	2,5	2	3	2	3	3	2	1
Question 10	2	2	1	3	2	1	2	3	3	2	1
Question 11	2	2	1	2	2	2	3	2	2	2	1

Those are the simplified results of questions 12 to 15 from the questionnaire. The results have been "simplified" by translating textual answers into keywords. The order of test persons remains the same as in the results for questions 1 to 11.

	1	2	3	4	5	6	7	8	9	10
Question 12	silent	sport	call doctor	care taker	meeting	physical work	loud	secret message	silent	sos
	loud	meeting		sport	secret message	care taker	silent		cinema	
	meeting	eating		handy unfitting		car			theatre	
		theatre							work	
		sex							no free hands	
		shower								
		car								
		in company								
		handy unfitting								
		motorcycle								
		cycle								
Question 13		plus leds	bell					plus leds	plus leds	
		numbers						acoustic signal		
		acoustic signal								
Question 14	repeat		plus leds	repeat	plus leds	cotton band	variable intensity	repeat		
	plus leds			cancel	numbers			cancel		
Question 15	auth-device			better fitting				other place on body	make it fashionable	individual signals
	rhythm based auth			better material*					make it cool	
									make it jewelry	

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