Pick, Drag, Hit and Drop – Does haptic design matter?

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Touch screen mobile devices are lacking natural haptic feedback compared to the traditional hardware keys. Researchers have found ways to produce tactile feedback to touch screens, but closer examination of what kind of feedback should be used with drag and drop context has not been done.

In this thesis the touch screen haptic feedback was studied in drag and drop context. Six designs with different drag, hit and drop feedback profiles were studied. Pick feedback was not in the scope of the study, but it was used as a minimum feedback in every design. The used design attributes varied between first three designs (1-3) which concentrated on the hit feedback and three last ones (4-6) which concentrated on the drag and drop feedbacks.

The results of the study showed that hit feedback was seen as the most useful method to add tactile feedback in drag and drop situation. Pick was also mentioned as a good feedback attribute, whereas the drag divided more opinions. It was seen that too strong feedback with drag is irritating, whereas soft continuous feedback could be used. Drop feedback was not clearly recognized as it was used with drag feedback.

Key words and terms: haptic, tactile feedback, drag and drop, UI design, mobile phones

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Kosketusnäytöllisten matkapuhelimien ja käyttäjien välisestä vuorovaikutuksesta puuttuu luonnollinen kosketuspalaute verrattuna mekaaniset painikkeet omaavaan laitteeseen. Tutkijat ovat löytäneet tähän ratkaisun tuottamalla mekaanisen painikkeen tuntuman keinotekoisesti erilaisten värinäpalauteteknologioiden avulla, mikä on parantanut kosketusnäyttöjen käytettävyyttä. Kuitenkin tarkempaa tutkimusta kaikista eri käyttökonteksteihin sopivista kosketuspalautteista, kuten raahaa ja pudota -tilanteessa, ei ole tehty.

Tässä pro gradu -tutkielmassa tarkasteltiin raahaa ja pudota -tilanteen kosketuspalautesuunnittelua kuudessa erilaisessa toteutuksessa käytettäyystutkimuksen avulla. Toteutukset vaihtelivat poimi- (pick), raahaa- (drag), törmää- (hit) ja pudota- (drop) ominaisuuksien välillä, joista poimimspalaute pysyi samana jokaisessa toteutuksessa. Testissä käytetyt palauteyhdistelmät jakautuivat kahteen osaan: törmäyspalautteeseen, johon ensimmäiset kolme (1-3) toteutusta keskittyivät, sekä raahaa ja pudota -palautteisiin, jotka olivat tarkastelussa lopuissa kolmessa toteutuksessa (4-6).

Käytettävyystestin perusteella törmäyspalautteen koettiin olevan hyödyllisin koskeutuspalautteen muoto raahaa ja pudota -tilanteessa. Myös poimimispalaute nähtiin hyödyllisenä ominaisuutena. Mielipiteet raahauksen aikana saatavasta palautteesta vaihtelivat käyttäjien kesken. Liian voimakas jatkuva palaute raahauksen aikana koettiin ärsyttävänä, kun taas kevyempää palautetta pidettiin mahdollisena. Koska pudota ja raahaa -palautteet tutkittiin samojen toteutusten avulla, pudotuspalaute nähtiin vaikeana erottaa käytön aikana.

Avainsanat ja termit: haptiikka, koskeutuspalaute, raahaa ja pudota -tilanne, käyttöliittymäsuunnittelu, matkapuhelimet

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1. Introduction

We experience the surrounding world through our senses. Seeing, hearing, smelling, tasting and touching introduce us to the things right from the birth. If we think about a newborn baby who has just arrived to the world, she does not see well or even hear well, but she senses different aspects of touch. She senses the temperature to feel if it is too cold or hot, the pain to inform if she is hurting somewhere and the touch that her loved ones give her, as well as the touch she produces herself. So the sense of touch has a special importance to us throughout our lives.

When I was young the computers and mobile phones were new. I got my first mobile when I was fifteen and my big brother and sister were complaining that they didn't have mobile phones when they were at the same age. Now my siblings have children and having a mobile phone at the age of seven is not a new thing. What has happened? Mobile phones have changed from luxury articles to utility articles. There are not so much landline telephones or telephone booths anymore and as mobile phones have replaced these public phones, a new communication culture has developed. Mobile phone is felt as more private and more personal equipment. Also the availability of people has changed as the mobile phones can be carried almost anywhere.

Not only the culture around communication has changed, but also the entire mobile world has lived through enormous changes during the years of economic boom. The requirements for mobile communication have followed the global winds of change and all the mobile brands have tried to hang on to these changes. The standard for mobile devices is getting more and more demanding: Smaller phones, more powerful, more intelligent, more user friendly, more accessible for everyone, and on top of these: touchable screens. There has already been some touch screen phones but Apple's iPhone revolutionized the field a few years ago. A New goal was set and all the mobile companies turned their concentration to the new standard. New race started to develop these small touch screens to be user friendly with all the goodies.

So how are the sense of touch and mobile phones linked together? Before the touch screen era, physical feedback from the hardware keys supported the use of mobile phones. The shape of the button, the mechanical feedback from pressing them and audio feedback helped to use the device. Now we have the touch screen boom, hardware keys are not used so much anymore and so one of our senses, touch is less used in the interaction between these devices and the user. This problem has been recognized widely and researchers have found a solution to this, which leads us to the point of this study: haptics.

To solve this lack of touch sensation in touch screens, researchers have developed a solution by producing artificial touch feedback, commonly known as haptic feedback. Research shows that by adding haptic feedback to mobile touch screens, the interaction experience improves [Brewster et al., 2007; Hoggan et al., 2008b; Koskinen, 2008; Poupyrev at al., 2002]. Haptics is already known around the world in different areas, for example, in entertainment industry, devices for visually impaired people and cars, but in mobile devices it hasn’t been used much as a solution for usability challenges arising from touch screens. Some of the brands have already used haptics as a touch feedback in some of their devices like LG and Nokia (Figure 1) but it is predictable that in the near future all the touch screens in mobile device industry use some kind of haptic feedback.

Figure 1 Nokia 5800 Xpress Music phone and LG KU990

1.1. Objectives of the study and research questions

Since the importance of haptic feedback in mobile touch screens has been established, there is no need to study that again. Instead, there is a lot of work to be done in the area of usefulness of haptic designs for different contexts. In this thesis the field of haptics is more closely studied in drag and drop context. The research questions are related to the different possible feedback locations and complexities of feedbacks which are introduced later in this thesis. The questions can be summarized as follows:

1. Do users find a simple haptic design more pleasant and useful than a complex one in drag and drop context?
2. Do users like to have feedback during a drag event?
3. What are the key events where to give feedback in drag and drop context?

1.2. Thesis structure

The first part, Chapter 2 consists of a literature preview which is divided into four different sections: usability, touch sense, haptics and design rules for haptics. The usability section introduces the general knowledge of what is the usability and how it has to be taken into account in user interface design. Touch sense section explains the physiology of touch. The haptics section consists of the explanation of the terms used around haptic feedback, introduction of commonly used haptic technologies and the design principles known in haptic design. Also most commonly used touch screen technologies are introduced in this section. The last section deals with different aspects affecting the design rules for haptics.

After the background the empirical part of the thesis begins. Chapter 3 introduces the arrangements, test equipment, participants, and actual tests, finishing with the test results. Chapter 4 contains discussion where after discussing the results and comparing them to earlier work and my own hypotheses, I will go through the results from a designer point of view. Chapter 5 is the summary.

2. Background

The background to this study has four themes; usability, sense of touch, haptics and design rules for haptics. In the usability section the general introduction for usability and user centered design is given. In sense of touch the physiology of touch is introduced. Presentation of haptics will concentrate on different research areas: haptics in mobile devices including haptic technologies and touch screen technologies introducing the used terms and parameters. Design rules for haptics section discuss the different aspects of haptic design process.

2.1. Usability

Usability, user experience, user-centered design and other terms used under Human-computer interaction (HCI) are hot topics of the day. Human-computer interaction is about designing computer systems that are safe to use and have high usability [Preece, 1994], but what is usability and most importantly, high usability?

2.1.1. Usability definitions

Nielsen [1993] defines the term *usability* as an attribute that evaluates *how easy a user interface is to use*. He defines usability via five elements*:* *learnability* – system is easy to learn for the user, *efficiency* – system is efficient to use, *memorability* – system is easy to use and remember, *errors* – low error rate and easy error recovery, and *satisfaction* – system is pleasant to use. Last element, satisfaction, can also be seen as social acceptability.

Soren Lauesen [2005] describes six factors of usability 1. *Fit for use* – system can support the real life tasks, 2. *Ease of learning* – system learnability, 3. *Task efficiency* – how efficient system is for most of the users, 4. *Ease of remembering* – how easy the system functions are to remember, 5. *Subjective satisfaction*, and 6. *Understandability* – does user understand how the system works. Lauesen also mentions *Ease of use*, which is combination of factors 2 to 6.

In *Handbook of User-Centered Design,* the International standard ISO 9241 defines usability as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.” The writers emphasize *effectiveness*, *efficiency* and *satisfaction* as important aspects of interaction: How does the user accomplish the tasks with the system? How easy it is for a user to accomplish the tasks with the system? And how does it feel to use the system? [Daly-Jones et al.,1997]

Preece [1994] suggests that the usability is a key concept in human-computer interaction and describes that the key point behind all HCI design and research is the idea that people should come first. The systems we use, should match to our requirements not vice versa. This same thought can be seen in Donald Norman's [2000] thinking, when he writes about the design of everyday things. Systems and interfaces should have high usability so users do not need to think too much how to use them. Preece [1994] summarizes the usability in systems as making them easy to learn and easy to use. She also introduces three-level process to accomplish good usability: first to *understand* how people use computers. After that to translate the understanding to tool and technique *development* to help designers ensure that the system is suitable for the tasks they are needed. And finally *achieve* efficient, effective and safe interaction between human-computer interactions. [Preece, pp. *15*] Preece [1994] lists the components of usability in the following way: *learnability, throughput, flexibility and attitude.* These can be connected to the other researchers like Nielsen's descriptions of usability. Learnability describes the time and effort spent on the task, throughput means task accomplishment, and flexibility of the system and attitude relate to the satisfaction to the system. [Preece, pp. *401*].

All of the above-mentioned definitions had the same aspects even though they varied a bit. Usability is finding the problems between a system and a user, to find solution to repair those problems and go one step further to avoid new problems. This can be found only by observing the usage between users and devices in their real life environment and understanding the interaction between a system and a human. High usability ensures that the usage of the system is easy from the beginning to the end, throughout the whole system even though the user changes. This needs understanding of various users, different user groups and cultures. It is hard to produce one system for all, but by observing different kind of users the most important aspects of the usage can be found and compromises can be done. High usability system enables learning and supports memory, and if errors occur it is easy to recover from them. The designers and usability engineers should have suitable tools and techniques to produce high usability systems. The consistency of the system or context-based logic helps user to remember how the system works. If an error occurs, be it rare; it should be easy to handle from user point of view. High usability system thus leaves an overall pleasant feeling as the user experience.

How system usability can be measured? For ensuring high usability, the usability testing should be done to the system and it should be involved in the entire system life-cycle [Lauesen, 2005]. There are different usability testing methods like heuristic evaluation, but as usability testing is the method used in this study it will be introduced below with other used methods.

2.1.2. Usability testing methods

Usability testing with real users is the most efficient way to get usability data. It provides information straight from the context where user uses the system, so it provides the understanding how users interact with the tested system. In usability testing there are two attributes which need to be taken into account: ***reliability*** and ***validity*** [Nielsen, 1993]. Reliability stands for the repeatability of the test results, and validity questions if the results really reflect the issues subject to the test. The reliability can be measured with statistical analysis as done in the test introduced in this thesis. Validity measures the relevancy of the results that can be used in real life products. Typical problems appear with the user selection: if the test tries to find out how average users use touch screen phones, we shouldn't qualify users who use touch screen phones daily. In this test validity was ensured by using selected user group and testing more than ten users.

Usability test consists of different usability methods which can be used during the test. In addition to methods, the test consists of the test tasks, test equipment, test environment, test participant, moderator and possible observers. The particular test setup used in this study is specified in more detail in Chapter 3.

Before testing, the purpose of the test should be clarified. **Formative evaluation** helps improve the system during the design while **summative evaluation** is done to finished system to assess the overall quality of it. [Nielsen, 1993; Preece, 1994] In this study the formative evaluation was used.

During the usability test **thinking aloud** method is often used [Nielsen, 1993; Lauesen, 2005]. Users thinking aloud enable moderators and observers to understand the ways they use the system. This also points out the misunderstandings user might have when using the system [Nielsen, 1993]. However, all the explanation offered by user should not be taken too seriously, as sometimes the usage tells more than the user even notices. For example user might spend long time with one task and then after finding the solution explain that he should have notice it before and it is very easy to do that. Here the system is not simple enough if the user does not find the solution, even though user thinks afterwards that it is easy. During the usability test introduced in this study, the thinking aloud method was encouraged.

Observation as a usability method is a simple way to collect usability data, but observer needs to be sharp not to prompt or interpret the user to follow the ideas observer has [Nielsen, 1993; Preece 1994]. Observation was used during the tests for this study.

Questionnaires and **interviews** are useful methods to find out the users subjective satisfaction, opinions and concerns of the test. The questionnaires are more useful to make right after the performance. Also there is a big difference if the user has actually tried the system the questions are related to or not. [Nielsen, 1993] There can be assessment form or open questions related to these two methods. With open questions user can tell the most pleasant and unpleasant parts of the test which can be very important when thinking the development of the system. In the usability test for this study both questionnaire and interviewing were used. The questionnaire had bipolar rating scales which are more specifically introduced in Chapter 3.

2.2. Sense of touch

Finnish health library [Terveyskirjasto Sitra, 2009] defines touch sense as an ability to feel the touch which is recognized by the receptors of touch from the skin or lining, and via the impulses from receptors touch has influence in the central nervous system. When one hears this definition at the first time, there might be still some questions and missing pieces to build a general view of the function of touch sense. To help build this general view it is good to start piece by piece starting from the more human-oriented point of view and finishing to the physiology point of view.

2.2.1. From human-oriented to physiology

Imagine your normal weekday: you wake up, eat breakfast, go to work, school or somewhere else, drink coffee while you are working, walk back home, hug your spouse or children, and so on. If we think this same day via touch sense, we can point out how important the sense of touch is for us. First when you wake up, you try to find the alarm clock with your hand even though your eyes are not open yet. We feel if the loved-one is still sleeping next to us and feel tightness of our muscles and joints during the first stretching. When we eat, besides we taste and smell, our linings feel the texture of the food and if it is cold or hot our sense of touch warn us about it.

When we walk or otherwise move, the movement of our joints and stretching of the skin tells us the position of our limbs. This is easier to think through another example. Imagine that you have an artificial leg downward from the knee. If there is no artificial feeling of the position of the leg, it is hard to know when it is bent and when straight. This can be emphasized more with the squeezing action: if one does not feel the object via touch sense it is hard to know the strength of squeezing.

Besides warning and helping our everyday actions, touch sense is also important aspect when thinking about feelings. Via touch we can communicate our feelings and sometimes we can feel the atmosphere even without touching. Think about your first time when you fell for someone. How did the first hand-by-hand walk felt and what about the first kiss? Being less romantic you can also think how cold or warm it was at that day. Would it be the same if you could just remember the vision, the smell, the taste and the sound of the moment? Touch sense enriches our everyday operations, helps us communicate and manage with different kinds of tasks. It warns us via sensation of pain and sensing the temperatures, informs the textures and shapes around us, and even helps us with our social relations. Upon understanding the role of touch sensation in our everyday life we can go on with the physiology of touch.

Touch sense can be divided into two sensations: **cutaneous** perception and **kinaesthetic** (i.e. kinesthetic) perception. Roughly explained cutaneous perception means the sense of skin and kinesthetic perception the sense of muscles (the perception means the same as sense or sensation) [Nurmi et al.,2001]. According to this definition, the terms cutaneous sense and kinaesthetic sense will be used. Cutaneous sense provides information of the stimulation that happens on the outer surface of the body and human perception of this sensation is called **exteroception**, while kinaesthetic sense provides information of the stimulation that happen within the body, and human perception of the body position and motion is called **proprioception** [Koskinen, 2008; Loomis and Lederman, 1986; McLinden and McCall, 2002; O’Malley and Gupta, 2008]. In exteroception the skin, eyes, ears, nose, etc. provide awareness of pressure, touch, temperature and pain. In proprioception muscles, joints, skin and efference copy, which is an internal copy of the predicted sensory feedback and resulting sensation from a motor command, provide awareness of static and dynamic body postures. [Kaaresoja et al., 2006; McLinden and McCall, 2002; O’Malley and Gupta, 2008] The awareness develops in sensory organs which contain nerve cells or sensory receptors that translates the sensory information to electrical activity. As a result the electrical activity travels to the nervous system and from there it is sent to the appropriate areas in the brain [McLinden and McCall, 2002].

2.2.2. Terminology

Furthermore to cutaneous and kinaesthetic sense there is also other terms used in this context. **Tactile perception** and **haptic perception** are terms which are often linked together. However, they differ: tactile perception pertains only to cutaneous sense and haptic perception pertains to both cutaneous and kinaesthetic sense. In cutaneous sense tactile perception pertains specifically to the sensation of the pressure and vibration. [Koskinen, 2008; Loomis and Lederman, 1986] (More about haptic and tactile definitions in Chapter 2.3.)

2.2.3. Cutaneous sense

In hand-held devices the role of cutaneous sense increases and that is why it is appropriate to examine it more deeply. What are the receptors in the skin and what are their tasks? Skin consists of two layers which are called *epidermis* and *dermis.* Epidermis is the outermost layer and consists of flattened cells. In some body parts epidermis can be more thickened than in others e.g. in the sole. Dermis is the inner layer and contains many particles: hair follicles, sebaceous glands, sweat gland, blood vessels and nerve endings. Also subcutaneous tissue can be classified as a part of skin and it consists mainly of connective tissue and grease [Gibson, 1962]. The nerve endings in dermis can be divided into three independent modalities according to the reaction to particular stimuli: *Mechanoreceptors* that respond to the pressure, touch, vibration and tickle, *thermoreseptors* that respond to temperatures and *nociceptors* that respond to the pain. [McLinden and McCall, 2002; O'Malley and Gupta, 2008] There are also two types of nerve endings: free nerve endings and nerve endings which are incorporated within the reception structures. These structured receptors are *Meissner's corpuscles, Merkel's disks*, *Pacinian corpuscles* and *Ruffini corpuscless*. In addition to these, hairy skin has the hair root plexus that detects if the surface of the skin is moving. Each of these receptors has their own way of responding to the touch and the combination of their behavior generates the touch sensation. [Koskinen, 2008; O'Malley and Gupta 2008]

Mechanoreceptors are also classified by the rate of sensory adaptation. Sensory adaptation is experienced as a change in a stimulus, but specifically it is sensory system's adaptation to the repeated exposure to a specific type of stimulus [O'Malley and Gupta, 2008]. *Slowly adapting* (SA) receptors detect constant stimulus whereas *rapidly adapting* (RA) receptors detect only short pulses. Slowly adapting mechanoreceptors are Merkel's disks which provide information about the texture and pressure, and Ruffini corpuscles which react to the skin stretch but also contribute to the kinaesthetic sense and control of finger position and movement. Rapidly adapting receptors are Meissner's corpuscles which are sensitive to light touch and vibration under 50 Hz, and Pacinian corpuscles which are responsible of sensitivity of pain, and pressure. Pacinian corpuscles' lowest stimulus frequency is 200 Hz. [Koskinen, 2008; O'Malley and Gupta, 2008] Figure 2 shows a cross-section of a sample of a human skin. Merkel's disks and Meissner's corpuscles can be found in the upper layer of dermis, while Pacinian corpuscles can be found deeper in dermis, as well as Ruffini corpuscles. Meissner's corpuscles location in the body are lips, palms, soles and especially in the fingers and toes. Merkel receptors are located in fingers, toes, nose, hair follicles and linings of the mouth. Also Pacinian corpuscles can mainly be found in fingertips but also in joints, bones and internal organs. [Solunetti, 2009]

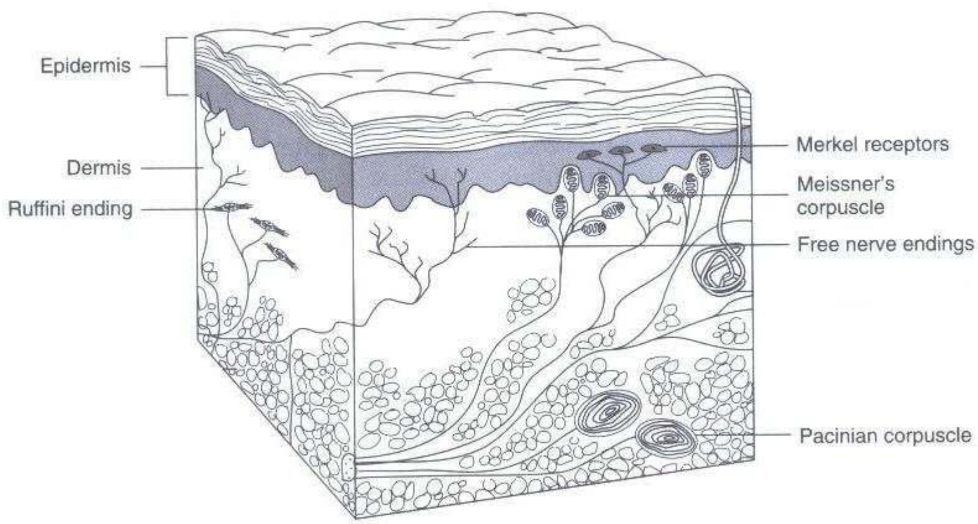


Figure 2 A cross-section of a human skin [Goldstein, 1999]

Mechanoreceptors have also different spatial resolutions. The degree of spatial resolution depends on the body location (how many receptors are found) and the receptive field size, which depends on how deep the receptor type lies in the skin. The deeper the receptor lies the larger is the receptive field. The field size varies from 1 to 2 mm^2 to up to 45 mm^2. And the larger the receptive field is the lower is the spatial resolution. As mentioned in the previous paragraph, the Pacinian and Ruffini corpuscles can be found deeper from dermis so it is not surprising that they have large field size and therefore low spatial resolution while Merkel disks and Meissner's corpuscles, which are located in the upper layer of dermis, have more accurate spatial localization. The table (Table 1) below summarizes the different mechanoreceptor types and their variables. [Solunetti, 2009; O'Malley and Gupta, 2008; Koskinen, 2008]

Table 1 Mechanoreceptor types

	Task	Adaptation type	Spatial resolution
Meissner's corpuscles	- sensitive to light touch and vibration under 50 Hz	RA, short pulses	High
Pacinian corpuscles	- sensitivity of pain, and pressure, - lowest stimulus amplitude is 200 Hz.	RA, short pulses	Low
Ruffini corpuscles	- skin stretch - contribute to the kinaesthetic sense and control of finger position and movement.	SA, constant stimulus	Low
Merkel's disk	texture and pressure	SA, constant stimulus	High

2.2.4. Active and Passive touch

To finish the touch sense chapter there is still one thing that should be introduced: active and passive touch. Active touch is seen as an object being touched which provides information about objects and surfaces in the environment while passive touch is related to the sensation experienced in the skin which provides only information of surface level of our bodies. Gibson [1962] called active touch as tactile scanning. This is how he described the action how one provides active touch: by touching and scanning actively the object and getting the touch stimuli that way (also called haptic stimuli). Passive touch is more “being touched” while active touch is “to touch”. Gibson [1962] also showed that active touch resulted in better object perception than passive touch. This can be true if we think about the diversity of touch sense when we manipulate some object with our hand versus if the object is just dropped to our skin surface. But there is also researchers who think that passive touch should not be forgotten totally when thinking about object perception [McLinden and McCall, 2002]. For example there are tactile pins which can provide tactile stimulus to the finger to indicate Braille, while user’s finger remains still. Even though the opinions and discussion of should these two touches be distinguished at all, it is good to recognize that there are different kinds of touches: I can touch and I can be touched. [Gibson, 1962; Koskinen, 2008; McLinden and McCall, 2002]

2.3. Haptics

Now when we have introduced ourselves to the world of usability and touch sense we can go on by introducing the background of haptics. This chapter collects together different aspects of haptic starting with the definition of relevant terms and often used parameters in creating the stimuli. After that, the introduction of relevant studies of haptics in mobile context and introduction of commonly used technologies is given.

2.3.1. Terms and parameters

Earlier in this thesis the term haptic has been introduced in different contexts: haptic perception, haptic feedback, haptic sensation etc. but also the term tactile has been mentioned. So how do these terms link together?

T. Kaaresoja and J. Linjama [2003] describe the word haptics to be used when the device produces actively touch sensation to the user. As mentioned in earlier chapters the sense of touch includes both cutaneous touch and kinaesthetic touch where cutaneous touch arises from the sensations of the skin and kinaesthetic touch sensations from the muscles, joints and tendons. Cutaneous touch is also called tactile perception; therefore haptic feedback that gives only cutaneous information is called **tactile feedback**. Feedback that gives kinaesthetic information can be evoked via **force feedback** where information is sensed via body position and movement. To summarize: Word haptic refers to the sense of touch which consists of both cutaneous and kinaesthetic touch, and haptic feedback consists of tactile feedback and force feedback. In hand-held devices the current implementations only provide tactile feedback and that is why this term will be used in this study. Figure 3 describes the relations of these different terms. [Koskinen, 2008; O'Malley and Gupta, 2008; Linjama and Kaaresoja, 2003; Kaaresoja, 2008]

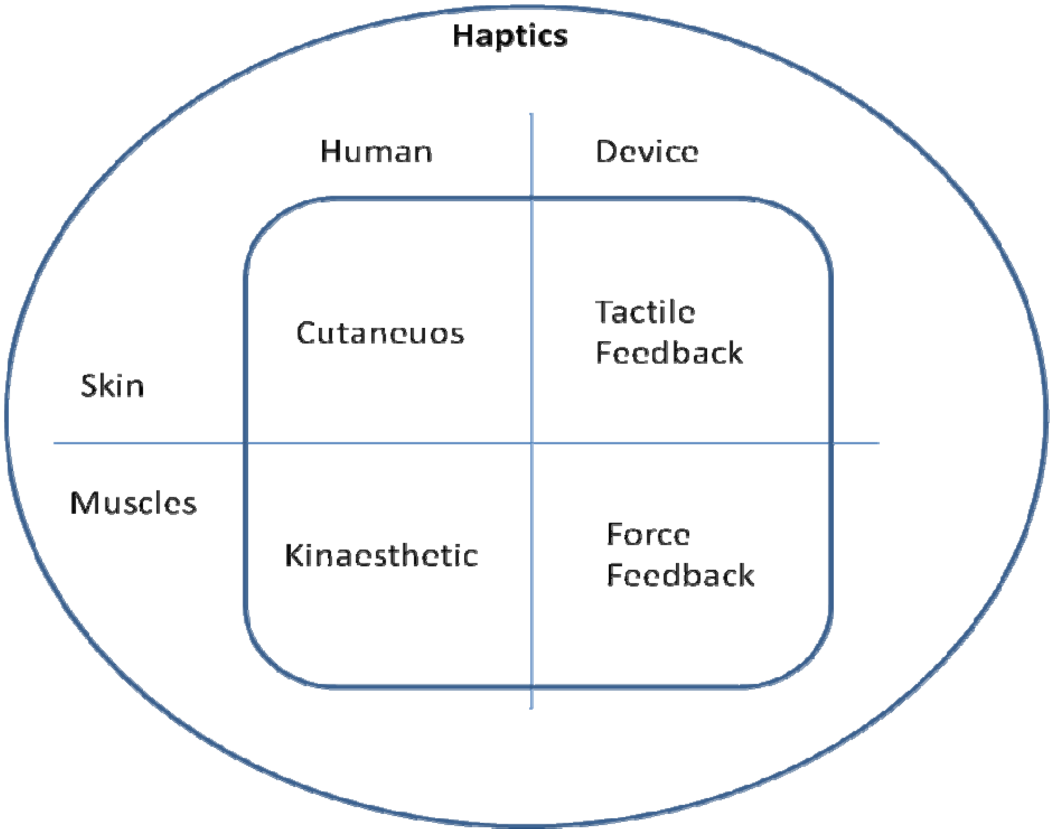


Figure 3 Relation between the main terms in haptics [Kaaresoja, 2008]

When exploring tactile feedback and tactile devices it is important to understand the possible parameters which build the feedback. Frequency, intensity, waveform, duration and rhythm are parameters which can be adjusted from the technological side, depending on the used technology [Brown et al., 2005; Kaaresoja, 2008]. In addition to these, *spatial location* has an influence to the sensation of a stimulus. In the existing hand-held devices the location of tactile feedback is hand which is hairless (glabrous) skin and has high sensitivity of touch. The most sensitive part is the fingertip [Brewster et al., 2008]. Therefore the spatial location is not separately specified here. The touch sensation of the stimulation is dependent on the individual sensing the stimulus. Ageing reduces the sensitivity as well as many diseases [Brewster et al., 2008] but also the personal sense varies between humans.

Frequency

Frequency indicates the number of repetitive events during a period of time. The unit of frequency is hertz (Hz) which indicates the number of events during one second. The frequency range for skin is 10-400 Hz and it is well known that the most sensitive frequency for palm is 250 Hz [e.g. Brown et al., 2005].

Intensity

Intensity or *Amplitude* is used to describe the strength of the vibration. The intensity can be measured, for example, in decibels (dB). The adjustment of intensity in tactile feedback should be left to the user, as the touch sensitivity varies between users. The relation between frequency and amplitude should be taken under consideration when designing tactile feedback, because the amount of recognizable levels in frequency can increase with the amplitude modifications (eight levels) [Brewster et al., 2008].

Waveform

Waveform i.e. timbre is a term that refers to the shape of the vibration wave. The shape of the waveform is often hard to identify. (Brown and others [2005] concluded that the changes in frequency enable to differentiate between levels of roughness). However, the waveform is more usable in the audio than in the tactile, since the different waveforms cannot be recognized in the skin so well. [Liimatta, 2008; Brown et al., 2005]

Duration

Duration describes the length of the vibration and is often measured by milliseconds (ms). While using duration in tactile feedback it is important to use a stimulus which is recognizable but not too long to feel slow [Brewster et al., 2008]. For example Kaaresoja and Linjama [2005] have found that the optimal duration of the short vibration pulse should be between 50-200 ms.

Rhythm

Rhythm is a variation of events and duration. It can be created by grouping together pulses which have different durations and pauses. The minimal time for human to detect two tactile stimuli is about 5 ms [Koskinen, 2008]. Rhythm is found to be very useful parameter with tactile messages [Brown et al., 2005].

2.3.2. Haptics in Touch Screen Mobile devices

In recent years the research on haptics in mobile devices has increased partly because of the new trend of touch screen phones. In this research area the tactile devices term is often used which indicates the use of cutaneous touch and more specifically the stimulus generated by skin indentation, vibration, skin stretch and electrical stimulation Brewster et al., [2008]. Poupyrev et al. [2002], Hoggan [2008b], MacLean [2008], Koskinen [2008] and other researchers have studied the importance of tactile feedback in interaction with hand-held devices and with touch screens, and all of them have come to the same conclusion: tactile feedback improves the usability.

2.3.3. Haptic technologies

When designing haptic feedback to the small touch screens the used technology is one important component. Poupyrev et al. [2002] have listed the minimum technical requirements of actuators used in hand-held devices:

1. **Size**, actuators should be small to fit to the small devices and not to increase the size of devices.
2. **Lightweight**, not to dramatically increase the weight of device.
3. **Low voltage** (~5V) and **low power consumption**, not to decrease the battery life dramatically and to be able to use in mobile devices.
4. **Ease in customization**, to be able to retrofit to different sizes and forms of devices.

In addition to these technical requirements, the actuators should also feel good. Although the sense of touch is personal sensation, some general rules can be set to assure satisfying feedback. *Fast response* to the touch is one requirement. The minimal time for human to detect two consecutive tactile stimuli is 5 ms. Second requirement is the *variable intensity*. Humans can differentiate a vast range of intensities of tactile stimulus even with low amplitudes (0.2 microns). The adjustment of the intensity is often left to the user, but the default levels and differentiations should be designed carefully as well as the actuator should ensure the possibility to do so. *Wide frequency bandwidth* is third requirement. Frequency has an influence to the tactile perception because of the way receptors process the information. The frequency range for skin is 10-400 Hz [Brown et al., 2005] but Pupyrev et al [2002] lists that ideal actuator should provide variable frequencies from 1 to 1000 Hz. The fourth and the last requirement Poupyrev et al. [2002] introduces, is the *multitude of different wave shapes*. They assume that humans are able to distinguish a wide range of tactile wave shapes based on the earlier studies of Gault (1924).

The *vibrotactile display* term refers to a device, which can produce vibration that user can detect. There are different technologies used to provide this vibration in hand-held devices and according to above-mentioned requirements we can examine the most common ones: vibration motors and piezo technology.

Vibration motors

At the moment vibration motors are the most commonly used technology in hand-held devices [MacLean, 2008]. There are different kinds of vibration motors like coin vibra, bar vibra and linear vibra, used hand-held devices on the market. These actuators are mostly used in mobile devices to produce alert-kind of feedback (e.g. ringing tone vibra and clock alarm vibra) but there are also phones which use this kind of actuator to produce tactile feedback while interacting with the touch screen; for example LG KU990 and Nokia Xpress Music phone 5800 (See figure 1) [Unwiredview, 2010; Mobiiliblogi, 2010]. The best known company for developing haptic technologies to mobile devices is Immersion [Immersion, 2010]. Immersion has licensed their technology to different mobile brands, like Nokia and LG [Reuters, 2010; Mobile Tech News, 2010]. Immersion's VibeTonz technology used in mobile phones gives more advanced opportunities for vibration motor usage.

Rotating vibration motor is normally a 4 mm thick and 10 mm long object which has eccentric mass in the end of the shaft (See Figure 4.). Since the mass is eccentric it starts to vibrate when the motor is turned on. The mass is often made of tungsten which has higher density than iron and therefore enables the object to be smaller. The motors are also lightweight so the first and second requirement of Poupyrev's list is fulfilled.

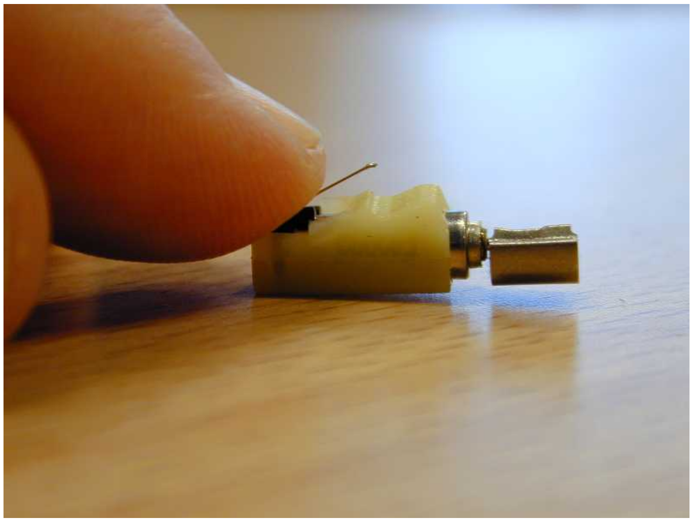
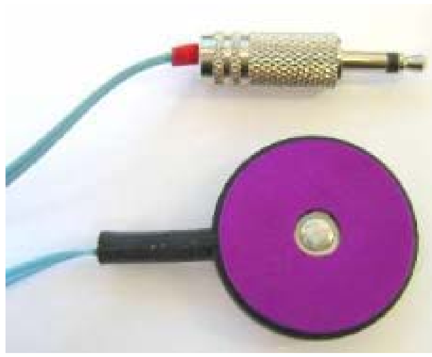


Figure 4 Picture of rotating vibration motor [Kaaresoja and Linjama, 2005]

The shape and size of the motor is very essential: the farther the mass midpoint is from axis the longer it takes time to start. When the motor gets voltage it starts to spin and shakes the mass in spinning direction. Therefore motor is normally placed to vibrate the phone in vertical direction. The placement and the size of the motor have effect to the feeling of vibration, but generally the feedback generated with vibration motor provides the feedback for whole device. That is why the feedback in touch screen interaction situation is felt in the hand holding the device instead of the fingertip interacting with the touch screen. The motor is driven at a nominal 1.5 Volts and a typical current is 60 mA. The voltage can be increased to 4 volts for a short duration. This makes the start-up quicker.

Linear vibration motor is another vibration motor. It is a round shaped metallic can, which size can vary. The moving mass moves up and down in the can between two springs. Next to the mass are magnetic coil and when voltage is conducted to this coil it makes the mass vibrate. The working principle is similar with a loudspeaker. [Nisula, 2008]



Pictur 5 C2 tactor, which is a widely used linear vibration motor [Brown et al., 2005]

Piezo Technology

Piezo technology is another well known technology which has been tested compared to the vibration motors. Piezo actuator consists of two layers: the first one is a brass layer and the other one is a kind of ceramic layer (See Figure 6). The first layer has opposite polarity to the second one and when voltage is conducted to this element it deflects the whole element and it bends. Usually the piezo element is placed between the device frame and display. When the element deflects it lifts the display up giving tactile feedback to the user.

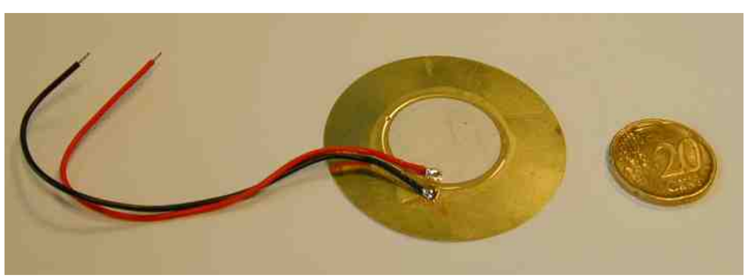


Figure 6 Picture of Piezo element [Koskinen, 2008]

Piezo element is faster than vibra motors and allows both the amplitude and the frequency of the feedback to be controlled at the same time. When vibra can take 30-40 ms to start, the piezo element can do it in 0.5 ms. Piezo element also allows controlling both the amplitude and the frequency of the tactile feedback at the same time, which makes the usage more flexible from vibra motors [Koskinen, 2008]. The biggest challenge with piezoelectronics is that it requires high activation voltages. This problem can be solved by adding more layers (i.e. multilayer piezo) but that also increases the size of the device. This might be the reason why it has not been used as a first option to produce tactile feedback in mobile devices yet.

The research results show that tactile feedback provided with piezo is experienced to be more pleasant than feedback provided with vibration motor [Koskinen et al., 2008]. The expressiveness of producing tactile feedback and the size are some of the reasons why the piezo is one step further in hand-held haptic technologies from vibration motors. For example, Poupyrev et al, [2002] have developed a TouchEngine from the requirements listed above and used piezo films to fulfill these requirements. Hoggan et al, [2008a] have also researched cross-modal combination where the results showed that using both piezo-electric and vibration motor technologies a totally new type of tactile sensation can be produced.

2.3.4. Touch screen technologies

Touch sensitive screens make the interaction between device and user very intuitive when the input and output, control and feedback are handled in one surface. Albinsson and Zhai [2003] list advantages and limitations of touch screens in their study of high precision touch screen interaction. Since the display works as a control surface, there is no need for extra input device e.g. mouse or space for the interaction. Other advantage they mention is that touch screens are more robust than free moving input devices. As a limitation there can be the fact that user’s finger, hand and arm can obscure part of the screen. Secondly, it is difficult to point targets which are smaller than the finger because the finger as a pointing device has very low resolution [Albinsson and Zhai, 2003]. This limitation has been recognized among industry using touch screen devices, and stylus pen has been used to solve this problem.

There are several touch screen technologies in the market, but mostly used technologies in mobile devices are capacitive and resistive displays. Other technologies are e.g. infrared and acoustic wave.

Resistive display consists of two layers: ITO (indium tin oxide) film and another ITO film or ITO glass. In generally ITO film is metallic, electrically conducted layer. These two layers has narrow gap between them and when user touches the surface of the touch screen the electrical current changes. This change is registered as a touch event and sent to the controller for processing. [NJY Touch Technology, 2010; Keuling, 2008; Touch Screens, 2010] Resistive technology is widely used, which might derive of its versatility and cost-effectiveness e.g. it is less sensitive to the scratches which easily incapacitate capacitive touch screens [Touch Screens, 2010].

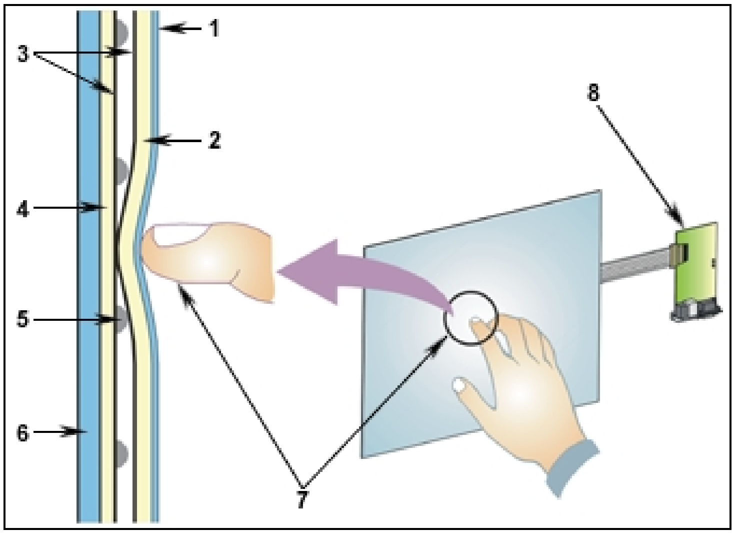


Figure 7 Picture of how resistive display works [Touch Screens, 2010]

1. Polyester Film

2. Upper Resistive Circuit Layer

3. Conductive ITO (Transparent Metal Coating)

4. Lower Resistive Circuit Layer

5. Insulating Dots

6. Glass/Acrylic Substrate

7. Touching the overlay surface causes the (2) Upper Resistive Circuit Layer to contact the (4) Lower Resistive Circuit Layer, producing a circuit switch from the activated area.

8. The touch screen controller gets the alternating voltages between the (7) two circuit layers and converts them into the digital X and Y coordinates of the activated area.

Capacitive display is an all-glass touch screen with transparent metallic conductive coating. The electrode pattern is printed along the edges distributing a low voltage field over the conductive layer. When the user touches the display and draws a minute amount of current to the point of contact, it creates a voltage drop. The x/y location of the touch point is calculated by the controller and transmitted to the computer [NJY Touch Technology, 2010]. Unlike resistive technology, capacitive shows self-calibration and multiple points of touch recognition. However, capacitive display has to be controlled with an object with current, so for example it cannot be used with gloves or fingernails.

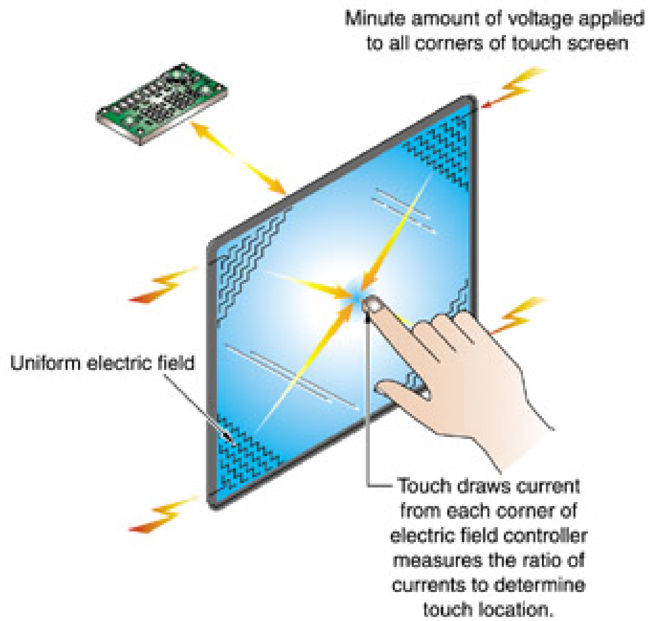


Figure 8 Picture of how capacitive display works [Touch screens display, 2010]

From tactile feedback point of view both of the introduced touch screen technologies can be used with different tactile technologies presented earlier in this chapter. The difference which was also seen in this study is the way to interact with different displays. As mentioned before, a capacitive display cannot be controlled with gloves or with most of the stylus pens, whereas resistive display can. The tactile feedback sensed via stylus pen, finger or gloves feels different. Also the accuracy of the display technologies affects to the haptic feeling: with resistive display user needs to press the display whereas with capacitive displays only light touch can make the action. A resistive display was used in this study

2.4. Design rules for haptics

The design of haptic feedback differs from the product design. In the book "*The design of everyday things*" Donald Norman [2000] defines that good design prefers feedback. But what are the guidelines for designing the feedback? There are many things that affect to the tactile device design to assure the high usability, but generally the definition of usability applies also to haptic design. Learnability, efficiency, memorability, satisfaction and errors defined by Nielsen [1993] are starting points to assure the usability in haptics design and to achieve these, there are different things that have to be taken under consideration during the design process.

2.4.1. Sense of Touch and haptic design

Taking the touch sense into consideration is one: how do the different stimuli affect the touch sensation via four receptors types and how can we manipulate the perception with design. To understand the limitations and opportunities that the touch perception gives is one aspect to better haptic design.

2.4.2. Technology and haptic design

Second aspect is the used technology. When we broadly know the most pleasant frequency and amplitude rates of human sense and the possibilities of different parameters, we need to think which technology gives the best tools to provide good tactile feedback. Not only to wait for a new technology to emerge, but also develop the available technologies like vibration motors. In addition to the type of technology, the location of vibration actuator or piezo element affects the sensation. This can be a challenging part for a product designer, if the hardware and software design are made separately, in which case the software designer needs to build the design on top of a predefined hardware. There are always reasons why the most user friendly user interface design cannot be used and this applies also to the haptic design side. The limits of technologies, tight timeframes and other reasons limit the freedom of design, but there is always possibility for new innovations.

2.4.3. Interaction and haptic design

Third important aspect of haptic design is the type of interaction. In mobile device there are many places where the tactile feedback can be given. The well known situations are vibrating alerts like incoming call, new message, calendar alarm and alarm clock. This kind of feedback can be separated from tactile feedback when user is actively interacting with user interface. The difference is the source of an input which produces the output (tactile feedback). Alert –like feedbacks can be described as *system generated feedbacks* that are presented using certain tactile icons. The other group where the source of input is the user can be called *user generated feedbacks*. In here, the touch event, gesture or some other input made by the user gets immediate feedback via haptics. This kind of separation is not official or even necessary, but it gives an idea of different possibilities of haptics used in mobile devices. There is also an issue how to separate the input between user and system, since the user adjusts the alerts, but this is rough separation which makes the closer examination easier.

2.4.4. Trigger points in haptic design

One of the key considerations in designing tactile feedback is to think where the feedback is triggered. With system generated feedbacks the tactile feedback is often some kind of rhythm or pattern indicating the different alerts. There are different possibilities to build the pattern, for example alerts where the vibra-alert follows the rhythm of the tone, but it is most often triggered to the action (e.g. clock alert). In user generated feedbacks there are two aspects to trigger the tactile feedback: the graphical user interface component (GUI component) and touch events. Graphical user interface is the system that provides the information via graphics to the user and is commonly used in mobile devices. Different components like buttons, lists and sliders constitute the solid user interface.

All the components have their own functionality which is manipulated via touch events. There are different ways to separate general touch events. One of them is to separate the pure touch events from touch event combinations. According to this classification there are only two pure touch events: touch down and touch release whereas there are many different touch combinations like drag and double tap. Poupyrev and Maryama [2003] defines five elements where to add feedback: *touching*, *dragging*, *holding*, and *lifting outside* or *inside* the GUI component. These same elements can be used in drag and drop context in this study:

Touching: Tactile feedback when user *touches down* on item.
Dragging: Tactile feedback when user *drags* the object or tactile feedback when user *drags* on top of the targets.
Holding: No holding feedback in drag and drop situation.
Lifting outside: Tactile feedback when user t*ouch releases* outside of object or target (feedback can vary depending on the context or functionality)
Lifting inside: Tactile feedback when user *touch releases* inside of object or target (feedback can vary depending on the context or functionality)

2.4.5. Relation to other feedback modalities

In addition to the difference of functions and touch events the GUI components vary also between graphical and audio feedback. For example buttons and lists do not look the same and that is one issue when thinking the haptic design: should the different graphical components also feel different? This is also one aspect of this study, to find out what users like when the feedback is modified differently depending on the graphical appearing and functionality.

There are also research results showing that the connection between audio and tactile feedback is important, even though the tactile feedback is more intimate feedback than audio which does not suite all situations (e.g. noisy, socially challenging situations). One important design aspect to haptic feedback is to think about the whole feedback experience. Mobile phone is a multimodal device where audio, graphical and tactual feedback can generate consistent wholeness which gives user much richer and useful experience than each of the modalities alone. However, in this study the role of audio has been limited via headphones used during the test, as only the haptic feedback is research subject. Also graphical feedback has been simplified.

Haptic feedback can also be used to make the users think or see differently than what actually happens on the screen. For example modifying the frequency and amplitude we can make the component effect feel different to what the graphical indication informs: adjusting the zoom slider can give increasing tactile effect even though the graphical indication of actual slider does not change. We can also compensate some visual needs, for example in long lists continuous pulse effect while dragging gives the idea of dynamically moving list even though the visual feedback can jump from page to page.

2.4.6. Estimation of the importance and usefulness of haptic design

In addition to trigger points of tactile feedback, there are also other aspects to think of. The importance and usefulness of tactile feedback in touch screens is also estimated via time used to the task, accuracy of the task and pleasantness of the feedback. Poupyrev et al [2002] have organized a design space for mobile tactile interfaces via two dimensions: the amount of *cognitive load* and the level of *abstractness*. If we think about situation where the user needs to walk at the same time while writing a message by using a touch screen device without tactile feedback, the interaction takes more cognitive load as it needs more focused attention. This same task is much easier if we can perform it with device which has mechanical keys. This same reliability and easiness of hardware keys is imitated in touch screen with tactile feedback, although the feeling of the real life button is missing. The level of abstractness in tactile design can be thought through real life metaphors. Mobile user interface is full of components from real life objects; for example slider to adjust the volume and different kind of buttons. However, there can be abstractions when imitating the feedback artificially, for example, instead of giving feedback with both touch events in button component (touch down and release), the feedback can be given only with touch down but it still is a metaphor from a real life button. In this study the time used to the task or accuracy of the task is not calculated. The main focus is the pleasantness of the feedback and the metaphor behind the designs is the real life situation where user moves an object from place A to B.

2.4.7. Emotions and haptic design

There is one more aspect to add when discussing haptic design: emotions. Touch perception in everyday lives invoke different kind of emotions. Thinking about the importance of touch and the earlier scenario of coming home and hugging your spouse or child, gives one example of this. There are different ways of measuring the emotions, for example heart rate, sweating and breathing, but it is hard to separate the strict emotions like sadness. One way to decode the measurements is to use affective space by Bradley and Lang [Salminen et al., 2008]. The three scales they use are: unpleasant-pleasant (i.e. valence), relaxing-arousing (i.e. arousal) and feeling of being controlled – being in control (i.e. dominance). Also motivation of avoiding or approaching something is important dimension [Salminen et al., 2008]. In this study user's subjective opinions and thoughts will be collected and measured via seven-point bipolar scales and interview.

Sense of touch, technology, interaction, parameters, trigger points, metaphors and emotions are all important aspects when designing haptic feedback. They all are related to each other and together they create a consistent experience to the user.

2.5. Research on haptics in GUI components

The research for finding the most pleasant tactile feedback for GUI components is in its infancy. The phase of proving the importance of having haptic feedback in touch devices is passed and the next steps have been the research of suitable technology and pleasantness of separate GUI component feedbacks like buttons. As mentioned in the technology overview, the piezo technology has proved to be a pleasant and accurate technology to produce tactile feedback in touch screens [Koskinen, 2008; Koskinen et al., 2008]. But it was also noticed that vibration motor and piezo technology together can generate totally new tactile sensations [Hoggan et al., 2008a]. In the GUI component pleasantness study area it seems that the most researched components are buttons in different contexts.

Most often one can find a research on keyboard or text entry context where the accuracy and effectiveness of feedback can be measured with error rates and time used to do the task. Koskinen [2008] used these measurement ways in addition to subjective ratings when examining the pleasantness of GUI buttons. The results showed that piezo feedback generated with 46 mA current was perceived most pleasant, and generally the piezo feedback compared to vibration feedback, made possible to enter numbers faster while fewer mistakes were made. Hoggan et al [2008a] studied the congruence between different kind of buttons and tactile feedbacks. The buttons differed visually in three ways: shape (circle - rectangle), size (small – large) and if the button was flat or upraised. The results showed that different kinds of buttons were connected to different feedbacks. Flat, small circular ones were connected to a soft piezo clicks but if the button was upraised, to soft vibration clicks. Large circular ones were both connected to the soft vibration clicks. Flat small rectangular buttons were connected to the sharper piezo click whereas raised ones were connected to the soft piezo click. Large rectangular buttons were connected to the sharp piezo click with flat ones and soft vibration clicks with raised ones.

The explanation between these congruencies is the connection between visual and tactile feedback. The vibration feedbacks are longer than piezo feedbacks and make the feedback rounder and are connected to the round shapes, whereas sharp piezo clicks were connected to the rectangular buttons. Softer piezo feedback was slightly longer than the sharp one and was connected to the small buttons. In the study where Poupyrev and Maruyama [2003] added tactile feedback to five touch events (touching, dragging, holding, and lifting outside or inside the GUI component), they observed that tactile feedback was the most effective in hold and drag situations, and that tactile was effective in interacting with small components. In addition to these studies there is not much research done to find the most pleasant tactile feedback combination to mobile user interfaces.

3. A study on *“Pick, drag, hit and drop – does haptic design matter?”*

This thesis concentrates on the tactile feedback in drag and drop situation in hand-held touch screen devices. The tactile feedback in Poupyrev and Maruyama’s [2003] study was seen effective in drag situations, where they used “click” feeling with it. The clicks were added to the next item indication, so in menus and scroll bars dragging a one step gave one click effect. Poupyrev and Maruyama’s solution seems logical as the indication of new item is given with click feeling. In drag and drop this same metaphor can be used when user hits the target. Tähkäpää and Raisamo [2002] studied tactile feedback in target situation with vibrating mouse. They tested four different feedback types: feedback on the target, feedback near the target (tremble is higher near the target), feedback far from the target (tremble is higher far away from target) and no feedback. There were no statistically significant differences between task times, but user feedback after tests showed that the users liked most the feedback on the target. This same hypothesis is assumed in this study: the design which indicates the hit is experienced more useful than one without.

There has not been much research concentrating on adding tactile feedback to drag and drop situation in hand-held touch screen devices. Kaaresoja et al [2006] presented a tactile feedback hand-held device with four applications extending the Poupyrev and Maruyama’s [2003] research: numeric keypad, text selection, scrolling and drag and drop. In the study by Kaaresoja et al. [2006] Snap-Crackle-Pop, the drag and drop mode was divided into seven actions.

1. user *picks* up the text document item,
2. user *drags* the object on the desktop,
3. user *hits* the folder object,
4. user hits the word processor object,
5. user *drops* the icon onto the desktop,
6. user drops the icon into the folder and
7. user drops the icon onto the word processor application and the application opens the text document.

This study is an extension of the paper by Kaaresoja et al [2006] (Snap-Crackle-Pop: Tactile feedback for mobile touch screens), where the main target is to find out what trigger points of drag and drop mode could be added haptic feedback into and would users prefer more complex or simple feedback types.

3.1. Test equipment

The study was made with a prototype hand-held touch screen device which has piezo actuators generating the tactile feedback. Kaaresoja et al presented [2006] similar device in their paper calling it "Snap-Cracle-Pop". Also Koskinen et al [2008] have used the earlier version of this device in their pleasantness studies. The size of the device is 143x73x21 mm and the size of the screen is 80x40 mm. The device was connected to the PC with data cable and display cable, so the software running in the device was adjusted from the PC (Figure 9). This enabled quick switch between the designs during the test. The software was written in Java.

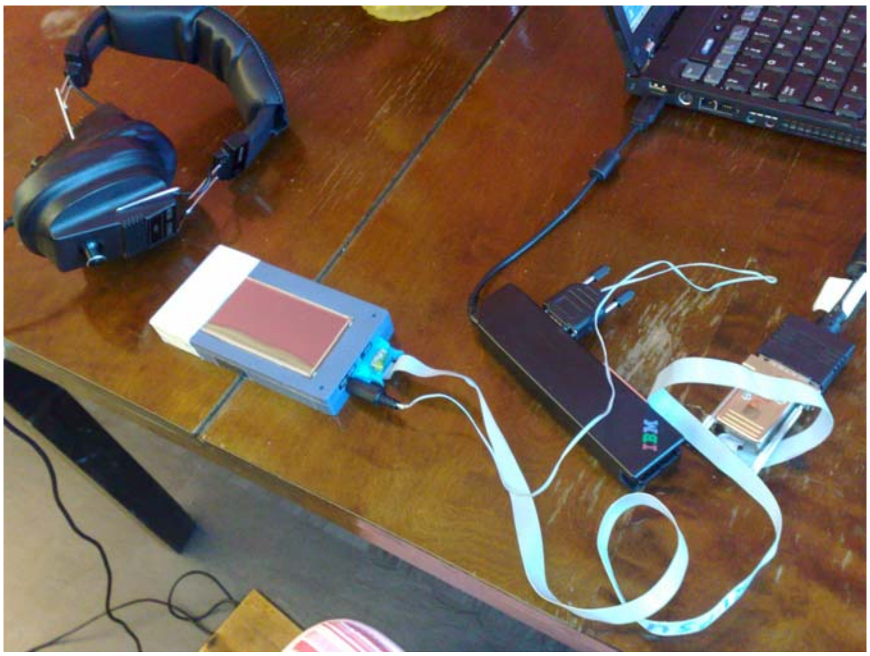


Figure 9 Test prototype connected to the laptop and headphones in a test environment.

The graphical UI was made as simple as possible but still to indicate real use cases. There were three icons which all were 4x5 mm in size. Red ball was used as an icon which can be dragged and dropped to two other icons. Another one of these two was a green square and another blue triangle where user could hit and drop the red ball (Figure 10).

Figure 10 Icons used in the study were red ball, green square and blue triangle.

Test users were advised to hold the device in dominant hand and interacting with the touch screen with the non-dominant hand. Users were asked to use fingernails when touching the screen, because of the touch accuracy, but as all of the users did not have long enough nails, the stylus was also introduced. Headphones were used as hearing protectors to block the user to hear the sounds coming from the device so user would concentrate to the tactile feedback (Figure 11). There were no music or other sounds played from the headphones during the test.

Figure 11 User in a test situation

The tactile stimuli of the device were created by controlling the sharpness, duration of the pulse and the duration of pause between pulses. There were four possible channels of sharpness: sharp, medium high, medium low and low, but only three of them were used in this study: medium high, medium low and low. The duration of the stimulus was possible to adjust between 0.125 ms to 31.875 ms and the duration of the pause between 1 ms to 100 ms. In this study the duration of the stimulus varied between 1.25 ms to 28.75 ms and duration of the pause varied between 1 ms to 10 ms.

3.2. Design background

Commonly known drag and drop mode can be divided in four attributes when thinking about haptic feedback: when the user **picks** the item, when the user **drags** it, when item **hits** the target, and when the user finally **drops** the item to the target. This same separation was seen in Kaaresoja et al, [2006]. So, the name of the whole process from tactile feedback point of view is a pick, drag, hit and drop, even though we know it more commonly by name drag and drop.

In this study there were six different designs to be tested and these designs differ between drag, hit and drop feedback. Pick feedback was not in the scope of the study, but it was used as a minimum feedback in every design. The used design attributes varied a bit between first three designs (1-3) which concentrated on the hit feedback and three last ones (4-6) which concentrated on the drag and drop feedbacks. The separation between these two groups was due to the technical limitations: the drag and hit feedbacks could not be tested in a proper way together. The idea behind the designs was to have one design *without* wanted research subjects (hit or drag and drop), one with *simple* feedback in wanted research subjects and one with *special* feedback in wanted design subjects. The designs in this study are also named based on these differences and research subjects: *Hit none*, *Hit simple*, *Hit special*, *Drag&Drop none*, *Drag&Drop simple* and *Drag&Drop special*. Table 2 describes the used attributes in each design.

Table 2 Description of actions giving tactile feedback in each design.

	Pick	**Drag**	**Hit**	**Drop**
Hit none	X			
Hit simple	X		simple	
Hit special	X		special	
Drag&Drop none	X	X		
Drag&Drop simple	X	X		simple
Drag&Drop special	X	X		special

The original plan was to use the same pick and the same drag feedbacks throughout the designs (where they would be needed), but after a usability test it was noticed that Drag&Drop none design was different from the other ones. After picking the red ball on the screen there were two different places to drag it: on top of the green square or the blue triangle. The idea behind the designs was to start from a simple design, add something more in the second round and make it more complex by the third round. So in Hit none design, there was only pick feedback, which was one pulse. Hit simple design has pick and hit feedbacks, which were both similar one pulse effects. And Hit special design has pick, which was one pulse, and variation of the two hit feedbacks between green square and green triangle. The first target, green square consisted of multiple sequential pulses and the second target, blue triangle consisted of two pulses where first one felt weaker than the second. Same pattern was used in designs concentrating to the drag and drop feedbacks. Drag&Drop none design has only pick and drag feedback, which were accidentally different than originally planned. The differences were that pick had two pulses instead of one and in drag the pulses distinguished during dragging more clearly than in the other drag designs. Drag&Drop simple design has drop feedback in addition to pick and drag. The pick and drop were both similar one pulse effects as used in Hit simple design. The drag feedback was smoother than in Drag&Drop none design, having less intensity and shorter pause between pulses. Drag&Drop special design had similar pick and drag effects as

Drag&Drop simple, but the drop feedbacks between green square and blue triangle vary similar way as in Hit special design. The first target, green square consisted of multiple sequential pulses and the second target, blue triangle consisted of two pulses where first one felt weaker than the second. The used parameters of each design can be seen in Tables 3 and 4.

Even though the Drag&Drop none design is distinguished from other drag and drop designs, there was only pick and drag given and the idea remained the same. However, the difference has to be taken into account when analyzing the results.

Table 3 Design parameters in Hit designs

	Parameter	Hit none	Hit simple	Hit special	
Pick	Description	Pulse	Pulse	Pulse	
	Sharpness	med low	med low	med low	
	Duration ms	28.75	28.75	28.75	
	Pause ms	10	10	10	
Hit Square	Description		Pulse	18 pulses sequentially	
	Sharpness		med low	low	
	Duration ms		28.75	1.25	
	Pause ms		10	1	
Hit Triangle	Description		Pulse	Double pulse	
	Sharpness		med low	med low	med low
	Duration ms		28.75	18.75	22.5
	Pause ms		10	100	10

Table 4 Design parameters in Drag&Drop designs

	Parameter	Drag&Drop none		Drag&Drop simple	Drag&Drop special	
Pick	Description	Double pulse		Pulse	Pulse	
	Sharpness	low	med high	med low	med low	
	Duration ms	12.5	0.625	28.75	28.75	
	Pause ms	100	40	10	10	
Drag	Description	Continuous pulses		Continuous pulses	Continuous pulses	
	Sharpness	med low		med low	med low	
	Duration ms	25		10	10	
	Pause ms	10		1	1	
Drop Square	Description			Pulse	18 pulses sequentially	
	Sharpness			med high	low	
	Duration ms			28.75	1.25	
	Pause ms			10	1	
Drop Triangle	Description			Pulse	Double pulse	
	Sharpness			med high	med low	med low
	Duration ms			28.75	18.75	22.5
	Pause ms			10	100	10

The order of the designs was mixed for every user. Table 5 shows the order of the designs with each user.

Table 5 Design order with each user

	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6
User 1 (pilot1)	1	2	3	4	5	6
User 2 (pilot2)	2	3	4	5	6	1
User 3	3	4	5	6	1	2
User 4	4	5	6	1	2	3
User 5	5	6	1	2	3	4
User 6	6	1	2	3	4	5
User 7	2	1	4	3	6	5
User 8	4	3	6	5	2	1
User 9	4	6	5	3	2	1
User 10	6	5	4	3	2	1
User 11	1	6	5	4	3	2
User 12	3	5	2	6	1	4
User 13	5	2	3	1	4	6
User 14	6	4	1	2	5	3

3.3. Research objectives

Detailed research objectives and hypothesies for the usability tests were:

1. Can the user tell any difference between different hit feedbacks?
Hypothesis: yes.

2. Which feedback type in hit situation is the most pleasant to the user?
Hypothesis: Hit special -design

3. Does drag feedback have any influence in the user experience?
Hypothesis: Yes. The assumption is that it disturbs the usage.

4. Do the users find simple haptic feedback design more pleasant and useful than a complex one?
Hypothesis: No. The user finds a complex haptic design (Hit special and Drag&Drop special designs) more pleasant and useful.

5. How do the users find the drop feedback?
Hypothesis: users find the drop feedback useful.

3.4. Test methods and arrangements

The usability of the designs was evaluated by conducting a usability test with actual end users. The field tests were carried out in home environment one-on-one, as observed session where a representative user performed tasks independently with test equipment. The test language was Finnish and a moderator was present in each session acting also as an observer.

Before each session, the user was interviewed (Appendix 1) and the test device was introduced. User was also instructed to concentrate on the feedback and feeling while using the device (Appendix 5). Quantitative data was collected from questionnaires after each task group (Appendix 3) and qualitative data from observations and interviews (Appendix 4).

In the questionnaire the participants were asked to rate the subjective experience evoked by the tactile feedback of each design using four seven-point bipolar scales varying from -3 to +3. Zero was thought as a neutral. The four values asked were:

1. lightness (heavy-light)
2. pleasantness (unpleasant-pleasant)
3. usefulness (useless-useful) and
4. logicalness (illogical-logical).

Repeated measures analysis of variance (ANOVA) was used for statistical analysis of the rating data. If the sphericity assumption of the data was violated, Sphericity Assumed corrected degrees of freedom were used to validate the respective F statistic. Least Significant Difference (LSD) corrected pair wise t-tests were used for post hoc pair-wise comparisons.

3.5. Test participants

14 participants took part in the study; seven males and seven females. The age of the participants varied between 23 and 56 years, average being 32 years. All the participants had minimum of one year experience with mobile phones and all of them used their phones daily. 13/14 of the users had some experience with touch screen devices, but only half of them had tried a touch screen mobile device. Three of the users owned touch screen mobile phone which they used daily. None of the participants had disabilities with sight or motor coordination. And as the test language was Finnish, all the test participants were Finns and had a good command of spoken and written Finnish. One of the users was left-handed, the others right-handed. Detail data from Pre-test questionnaire can be found from Appendix 2.

Five of the test participants had not heard about tactile feedback before. When they were asked what they think it might be, the answers were (translated from Finnish):

> *"It is some kind of vibrating thing."*
> *"It is an electric shock or something when pressing a wrong button. For real, some punch to your finger."*
> *"Would it give some kind of feeling to your finger?"*
> *"Maybe it is how it reacts to my touch?"*
> *"I don't know."*

Some of the users remembered it to be the vibrating alert in mobile phones and some of the users described it as a confirmation when doing an operation. One of the interesting comments was the idea of having feedback so one does not have to see the device, when it can be felt.

3.6. Test tasks

There were three tasks which were repeated six times and were given to the user one at a time. The tasks were performed in same order in each time and the user was asked to read them aloud at first time. The order of the designs varied between users (see Table 5). The tasks were:

1. Pick the red ball and drag it around the screen. After dragging a while, drag the ball about the same place it was in the beginning.
2. Pick the red ball and drag it on top of the green square. Drop the ball to the square.
3. Pick the red ball and drag it on top of the blue triangle. Drop the ball to the triangle.

The metaphor behind the graphical interface and its function is the same as in "Snap-Crackle-Pop" [Kaaresoja et al., 2006]: when user dragged the ball on top of the square and dropped it, ball disappeared into the square. This can be related to the situation where item is dragged on top of the folder and dropped in to it. When user dragged the ball on top of the triangle and dropped it, the ball disappeared into it and a bigger blue triangle appeared on the screen. This can be related to the situation, where a word file is dragged and dropped on top of the word application, the file is opened in the application. Third possibility was to drag the item to a new place on a desktop and drop it there. In this test drop to desktop feedback is used only in Drag&Drop simple design and Drag&Drop special design and it is the same as pick feedback. However, drop to the desktop was not included as a separate test task, but was given when the user returns the red ball in test task 1. The following list describes the comparison of drag and drop functionality in the Snap-Crackle-Pop and designs used in this study.

1. user *picks* up the red ball (word document),
2. user *drags* the object on the desktop,
3. user *hits* the green square (folder),
4. user hits the blue triangle (word application),
5. user *drops* the icon onto the desktop,
6. user drops the icon into the green square (the red ball disappears to the square)
7. user drops the icon onto the blue triangle (the red bal disappears and bigger blue triangle opens)

Table 6 and 7 shows the focus of each test task. In the last column the hit or drop feedback type can vary between these three; one being none, two being simple one-pulse design and three being more complex, where feedback type differs between triangle and square.

Table 6 Focus of the hit test tasks

	Task	**Focus**	**Hit Feedback types in Designs**
1	Pick the red ball and drag it around the screen. After dragging a while, drag the ball about the same place it was in the beginning	To introduce user to device and give overview of feedbacks.	1. None (Hit none) 2. Simple (Hit simple) 3. Special (Hit special)
2	Pick the red ball and drag it on top of the green square. Drop the ball to the square.	To test hit feedback, where item is dropped inside.	1. None (Hit none) 2. Simple (Hit simple) 3. Special (Hit special)
3	Pick the red ball and drag it on top of the blue triangle. Drop the ball to the triangle	To test hit feedback, where item is opened after dropping.	1. None (Hit none) 2. Simple (Hit simple) 3. Special (Hit special)

Table 7 Focus of the drag and drop test tasks

	Task	**Focus**	**Feedback types with drag and drop in Designs**
1	Pick the red ball and drag it around the screen. After dragging a while, drag the ball about the same place it was in the beginning	To introduce user to device and give overview of the feedbacks.	1.None (Drag&Drop none) 2. Simple (Drag&Drop simple) 3. Special (Drag&Drop special)
2	Pick the red ball and drag it on top of the green square. Drop the ball to the square	To test drag feedback and drop feedback, where item is dropped inside.	1.None (Drag&Drop none) 2. Simple (Drag&Drop simple) 3.Special (Drag&Drop special)
3	Pick the red ball and drag it on top of the blue triangle. Drop the ball to the triangle	To test drag feedback and drop feedback, where item is opened after dropping.	1.None (Drag&Drop none) 2. Simple (Drag&Drop simple) 3. Special (Drag&Drop special)

3.7. Test results

After each design, users filled in the questionnaire where they rated the subjective experience evoked by the tactile feedback of each design using four seven-point bipolar scales (see Chapter 3.4). The four attributes measured were: Lightness, Pleasantness, Usefulness and Logicalness. In this Chapter test results will be presented first through these four values and after that through each design.

3.7.1. Lightness, Pleasantness, Usefulness and Logicalness

In the questionnaire the scale for lightness was from heavy to light. Next figure (Figure 12) shows the results of the first measured attribute, Lightness.

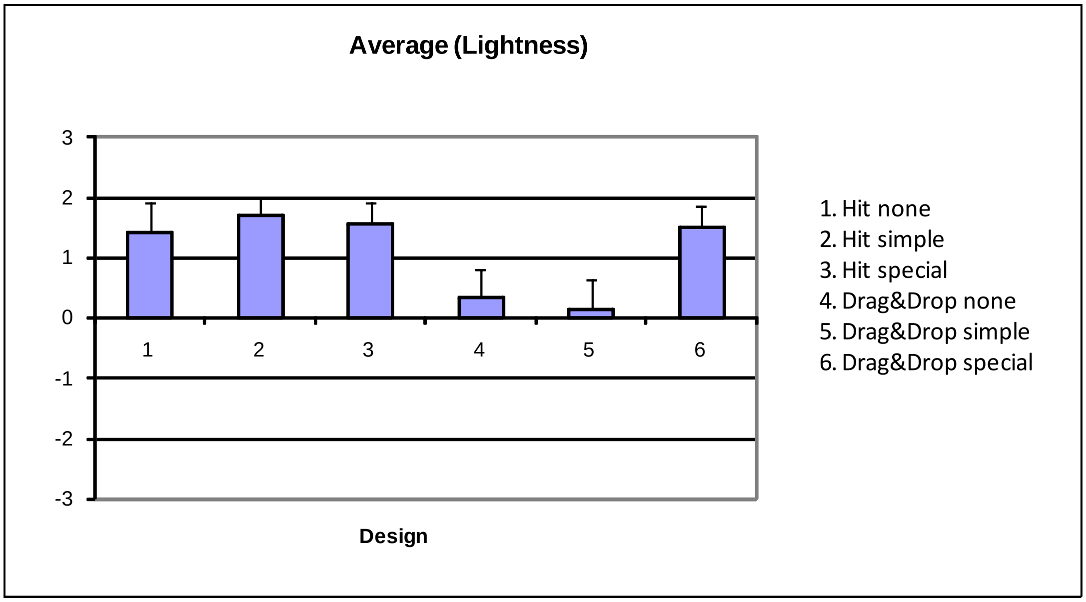


Figure 12 Lightness between the Designs

A one-way repeated measures ANOVA revealed a statistically significant main effect ($F(5) = 3.250$, $p < .05$) for the lightness rating of the designs. Post-hoc pair-wise comparisons LSD showed significant differences in lightness ratings between Designs 2 and 4 (MD = 1.357, $p < .01$), 2 and 5 (MD = 1.571, $p < .01$), 3 and 4 (MD = 1.214, $p < .05$), 3 and 5 (MD = 1.429, $p < .05$), 6 and 4 (MD = 1.357, $p < .05$), and also between Designs 6 and 5 (MD = 1.143, $p < .01$). However the result of Design 1 did not have statistically significant difference in the lightness evaluations between other designs.

Table 8 Mean difference and significance level of designs with statistical significance in Lightness attribute

Designs	Mean Difference	Significance level
2 and 4	1.357	0.009
2 and 5	1.571	0.007
3 and 4	1.214	0.015
3 and 5	1.429	0.05
6 and 4	1.357	0.029
6 and 5	1.143	0.002

Second measurement value was **pleasantness** of the feedback. In the questionnaire user was asked if the tactile feedback effects feel unpleasant or pleasant. Next figure (Figure 13) shows the results of Pleasantness.

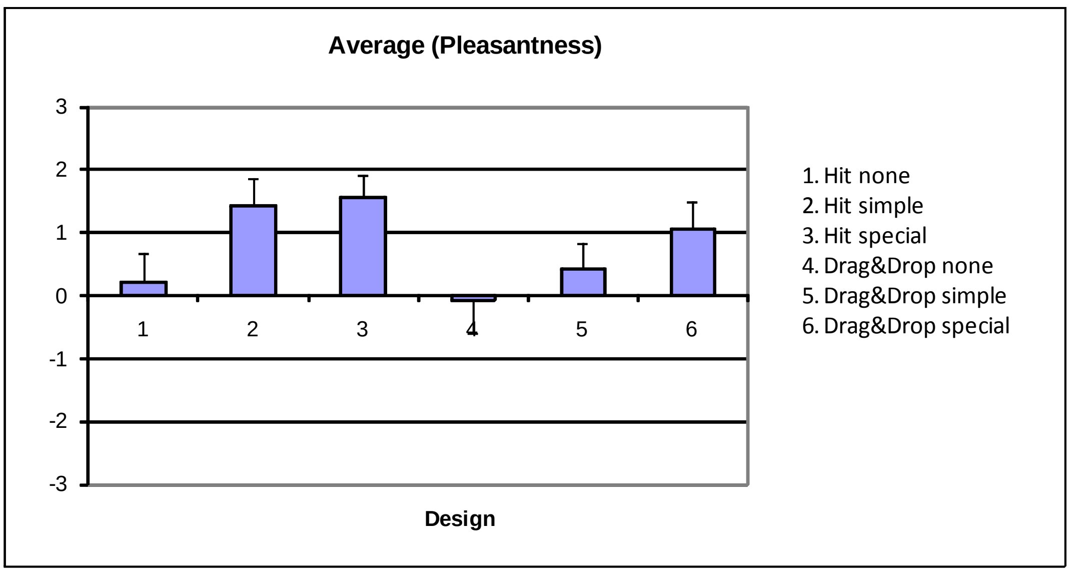


Figure 13 Pleasantness between designs

A one-way repeated measures ANOVA revealed a statistically significant main effect (F(5) = 2.548, p < .05) for the pleasantness rating of the designs (Figure 6). Post-hoc pair-wise comparisons LSD showed significant differences in pleasantness ratings between Designs 3 and 4 (MD = 1.643, p < .001). Also the Designs 1 and 3 (MD = -1.357, p = .055) and designs 2 and 4 (MD = 1.5, p = 0.052) approaches significance.

Third value to be measured was **usefulness** of the feedbacks. In the questionnaire user was asked did the tactile feedback effects feel useless or useful.

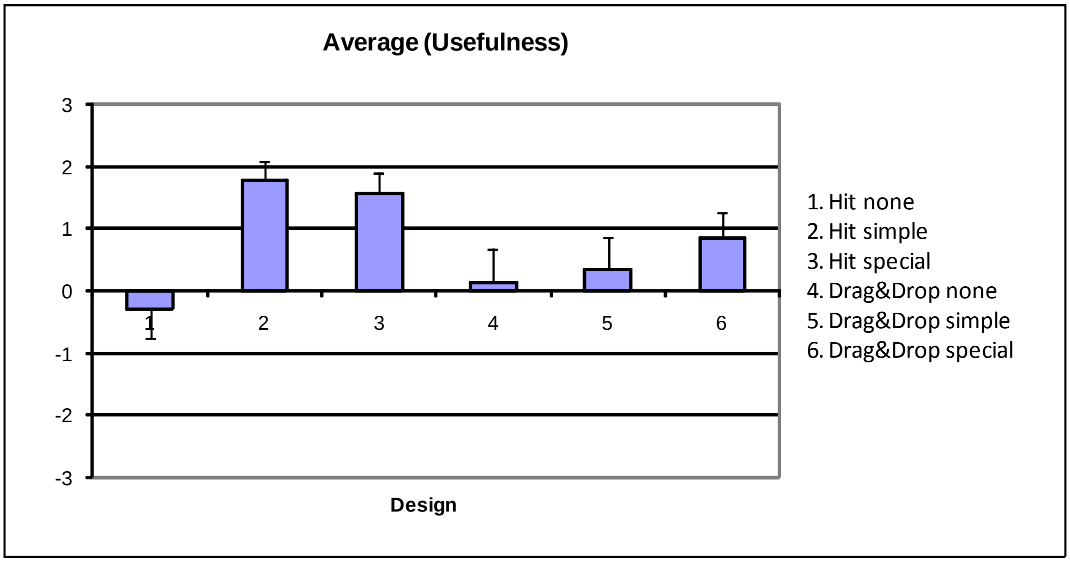


Figure 14 Usefulness between designs

A one-way repeated measures ANOVA revealed a statistically significant main effect ($F(5) = 3.480$, $p < .01$) for the usefulness rating of the designs (Figure 7). Post-hoc pair-wise comparisons LSD showed significant differences in pleasantness ratings between Designs 1 and 2 (MD = -2.071, $p < .01$), 1 and 3 (MD = -1.857, $p < .01$), 2 and 4 (MD = 1.643, $p < .05$). and 2 and 5 (MD = 1.429, $p < .05$).

Last value to be measured was **logicalness**. In the questionnaire user was asked did the tactile feedback effects feel illogical or logical.

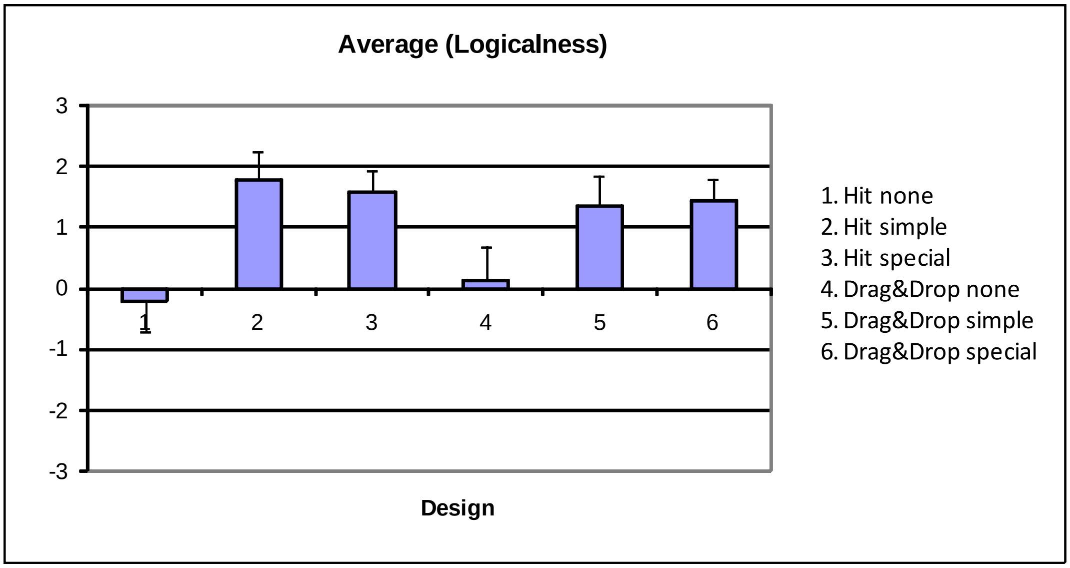


Figure 15 Logicalness between designs

A one-way repeated measures ANOVA revealed a statistically significant main effect ($F(5) = 3.045$, $p < 0.05$) for the logicalness rating of the designs (Figure 8). Post-hoc pair-wise comparisons LSD showed significant differences in pleasantness ratings between Designs 1 and 2 (MD = -2.0, $p < .01$), 1 and 3 (MD = -1.786, $p < .05$), 1 and 6 (MD = 1.643, $p < .05$), and 2 and 4 (MD = 1.643, $p < .05$).

3.7.2. Results per design

The following diagram (Figure 16) summarizes the results of the post-test interview for Hit none design. According to the test results Hit none design was seen as a light design, but the usefulness and logicalness were rated significantly low.

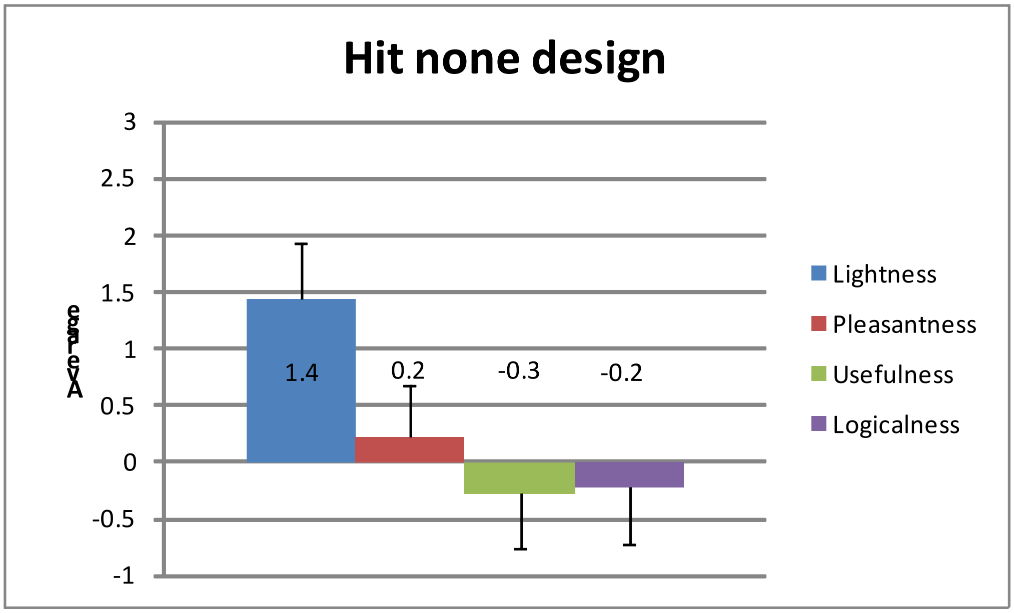


Figure 16 Ratings for Hit none design

The Figure 17 below summarizes that Hit simple design was seen more light, useful and logical than pleasant.

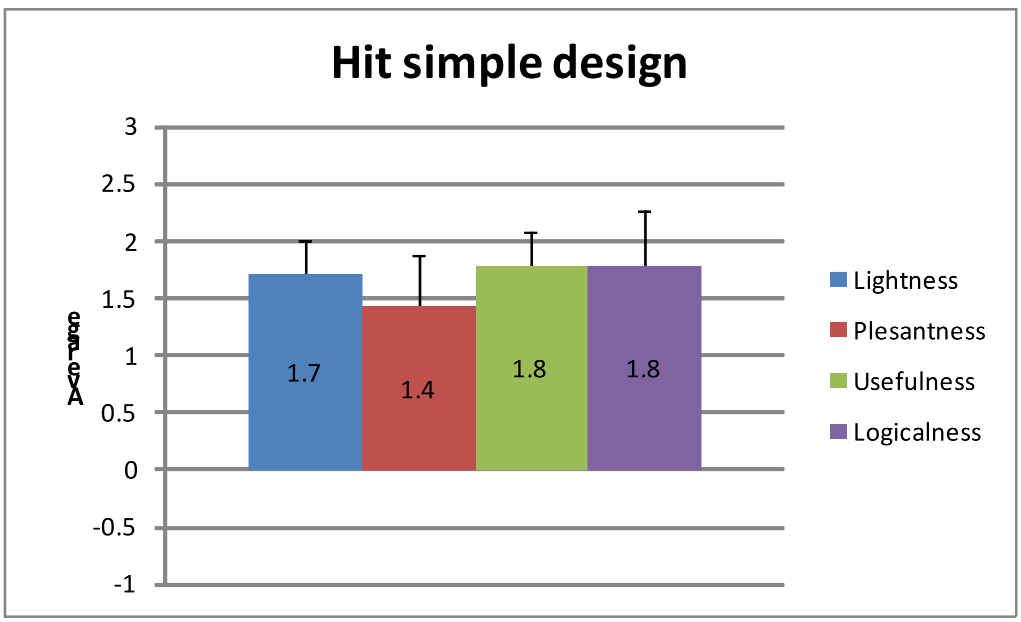


Figure 17 Ratings for Hit simple design

Next figure (Figure 18) summarizes that Hit special design was rated equally between all values.

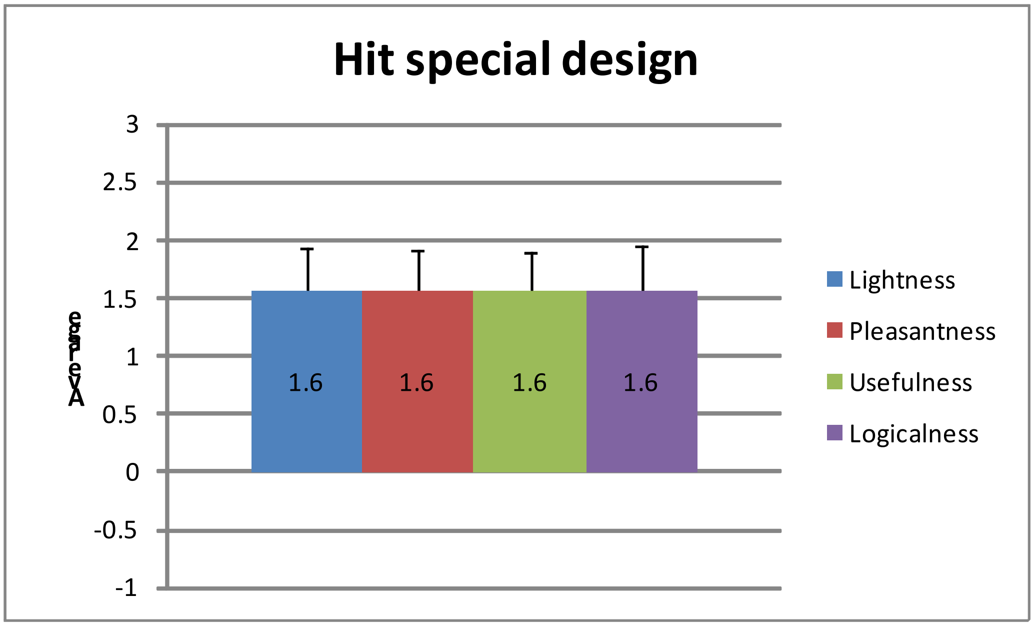


Figure 18 Ratings for Hit special design

Figure 19 summarizes that Drag&Drop none design was rated more light than pleasant, useful or logical. However, the Drag&Drop none design was rated low compared to the other designs.

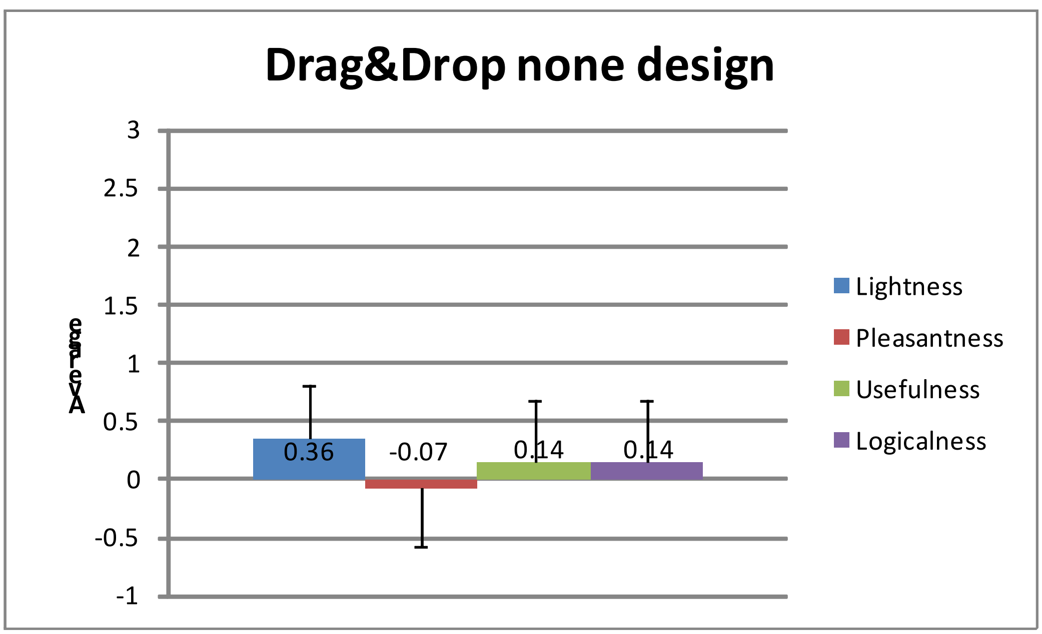


Figure 19 Ratings for Drag&Drop none design

Figure 20 summarizes that Drag&Drop simple design was seen logical rather than pleasant or useful.

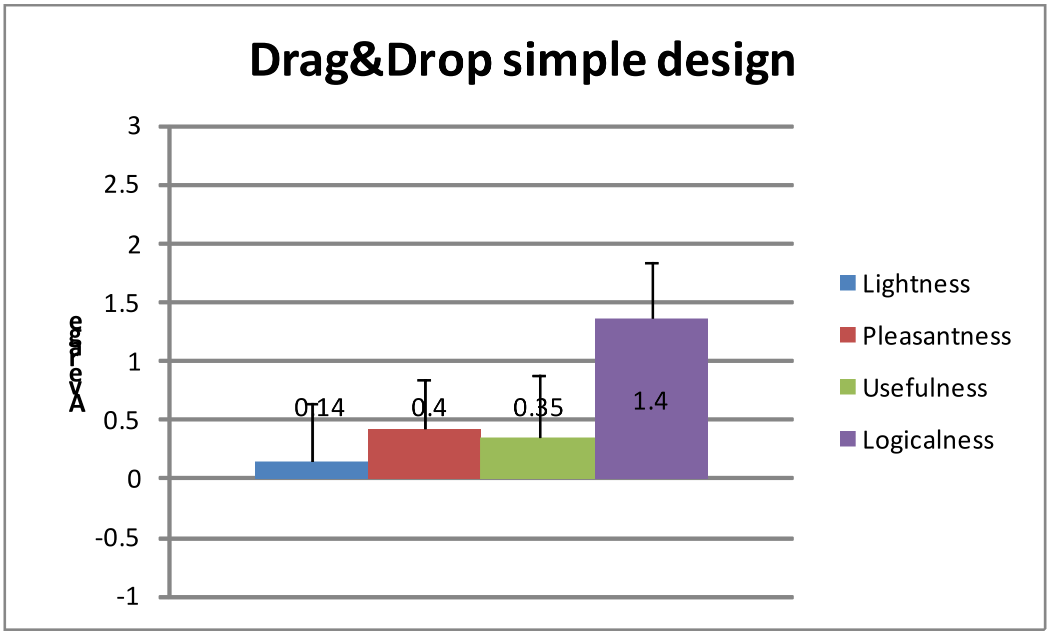


Figure 20 Ratings for Drag&Drop simple design

Figure 21 summarizes that Drag&Drop special design was felt light and logical, but also pleasant and useful.

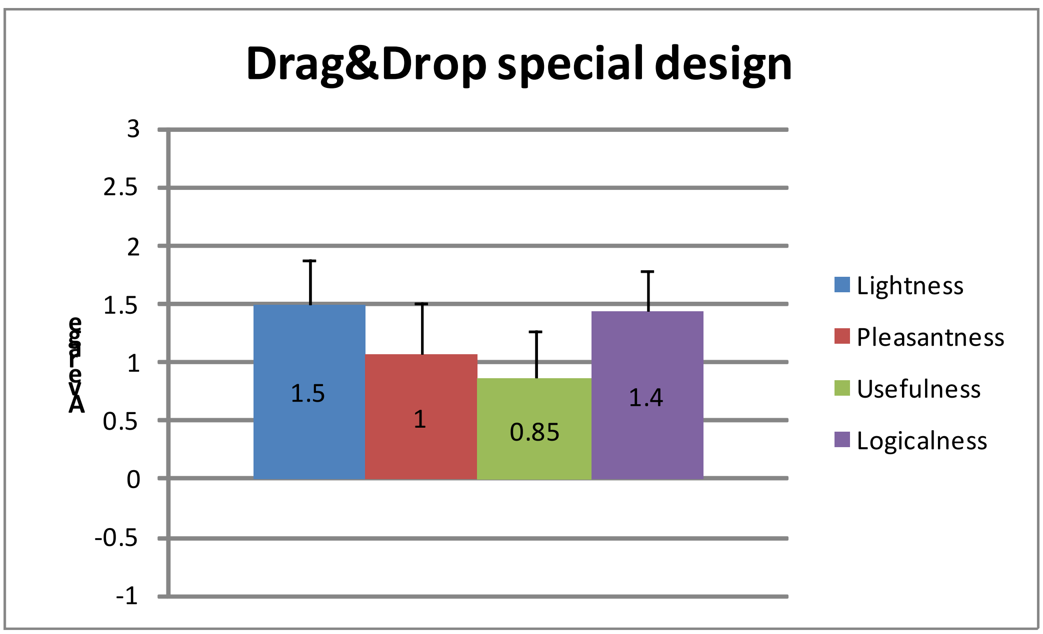


Figure 21 Ratings for Drag&Drop special design

4. Discussion

The main purpose of this usability study was to explore the feasibility of haptic design in drag and drop context. There were four different user actions where tactile feedback could appear in: pick, drag, hit and drop. This study concentrated mainly on the drag, hit and drop feedbacks, even though the pick was also used. There were two different set ups designed, one concentrating on the hit feedback and other concentrating on the drag and drop feedback. There were three designs in each set up where the amount and complexity of feedbacks grew between these three designs. Similar pick feedback was used in *Hit none*, *Hit simple*, *Hit special*, *Drag&Drop simple* and *Drag&Drop special* designs. The *Drag&Drop none* design had double pulse feedback in pick action by accident.

The six designs were tested with fourteen participants in three test tasks. The order of the designs varied between the users. All the designs were rated by user via bipolar scale (-3 to 3, where 0 was seen as a neutral) of lightness, pleasantness, usefulness and logicalness. A one-way repeated measures ANOVA revealed statistically significant ($p<0.05$) in every evaluated value, which proves the meaningfulness of designing tactile feedback.

4.1. Discussion on the rated attributes

Lightness as a measurement *value was found to be hard to understand*. In the questionnaire the scale was from heavy to light. The Drag&Drop none and Drag&Drop simple designs were experienced to be the heaviest. Both of them had the drag feedback which can partly explain the result. However, the Drag&Drop special design which also has the drag feedback was rated almost as light as the Hit special design, which didn't have the drag feedback.

Some of the users thought that the feedbacks felt good but still said that they felt heavy. Some of the users thought that the lightness is neutral as they did not know what it meant, while some said it has to be light as it feels good. The lightness was also valued with the feeling *how fast it was to do the tasks*. Some of the users commented that interaction felt really fast and gave three points to the design when rating the lightness. Same thing was seen with test rounds where users had problems to pick up the red ball, which made the interaction more slow and sticky. So ***the lightness of the feedbacks would not be the best possible evaluation attribute in this kind of study***.

Pleasantness as a measurement value was felt more natural to answer than the lightness, even though sometimes the *users felt it hard to compare the pleasantness between designs*. In pleasantness ratings the designs which did not have drag feedback were seen more pleasant than the ones that did. Nevertheless, the Hit none design, which did not have any other feedback than pick, was not rated high in pleasantness point of view. Drag&Drop none design was statistically significantly less pleasant compared to Hit simple and Drag&Drop none designs, and Hit special and Drag&Drop none designs. Thi might be explained with the fact that the Drag&Drop none design differed from other drag designs by accident. Pick was a double pulse feedback instead of a one pulse and the drag feedback was stronger and rougher than in Drag&Drop simple and Drag&Drop special designs. This finding supports the assumption that ***haptic design does matter***.

In **usefulness** ratings, the Hit simple and Hit special designs were statistically significantly more useful compared to the other designs. Both of these designs had hit feedback and no feedback when dragging, so users rated the hit feedback to be more useful than other feedbacks. Even the Hit none design which had only pick feedback was not seen useful by itself and was rated lowest when asking usefulness. Interesting was that statistically more useful was the Hit simple and Hit special compared to the Drag&Drop special. The results of usefulness attribute support the results of earlier studies (see more in Chapter 4.3) that ***the hit the target is the most useful feedback from user point of view.***

When rating **logicalness**, the Hit simple, Hit special, Drag&Drop simple and Drag&Drop special designs were rated more valuable than the remaining designs, which did not have any feedback in hit or drop events. This suggests ***feedback informing user of hitting or dropping the item is seen more logical than pick or drag feedback***. Hit simple design was rated the most logical design, so the value of the different effects when hitting or dropping the item in square or triangle was not seen logical. Interesting is that the Drag&Drop special design in logicalness was statistically significant compared to the Hit none design (and also the Drag&Drop simple was rated high, even though it didn't differ statistically from other designs) and it has the drag feedback. This result combined with the interviews proves that the ***sophisticated effect during dragging is perceived as a logical feedback.***

All of the users saw tactile feedback as a good feature when it is used in correct places. Despite the fact that it is hard to please all users when it comes to tactile feedback, the test results gave some hints which places are most liked in drag and drop mode. Hit simple design got the highest scores on lightness, usefulness and logicalness, whereas

Hit special design got more scores on pleasantness. This shows that ***hit feedback was the most preferred in drag and drop situation.*** Drag&Drop simple and Drag&Drop special designs got high scores in logicalness, so also the drag and drop feedbacks were seen logical. However, ***designs which did not have any feedback on hit or drop situation were rated lowest.*** Hit none design got high lightness scores whereas Drag&Drop none design did not have high scores in any of the ratings. High lightness scores of the Hit none design can be explained with user comments, where they described the continuous feedback during dragging to be heavy. This was especially seen with Drag&Drop none design, which had accidentally stronger drag feedback than other two drag design cases. The lightness was in generally seen hard value to rate, so this might also explain the result.

4.2. Discussion about each design

Hit none design had only pick feedback which was short pulse effect when user touched down on top of the red ball. The comments from users varied depending on the design order. If the user had tried other designs before Hit none design, they could compare the feeling between designs. Many of the users commented that the pick feedback was good and helped to understand when the red ball was picked. However, many of the users who had tried a more complex design before Hit none design described it with words boring and trivial. In addition to those, three of the users commented that they miss the feedback while dragging or hitting now, when they have got used to it. Four of the users considered the graphical feedback as a good indication when dragging and dropping the red ball, two of them did not miss haptic feedback at all with dragging and dropping actions.

Hit simple design consisted of two separate feedbacks appearing with pick and hit actions. Some of the users saw the hit feedback to be truly logical and useful, whereas some of them didn't feel the same way. Three of the users commented the visual feedback to be enough, even though the haptic feedback was not seen disturbing. One of the users thought that the feedback was too weak when hitting, whereas another user felt it to be too strong. The hitting point of the items was not so clear to the users. Some of the users thought that the feedback appeared when they were on top of the square or triangle and some recognized that the feedback was given from the edge of the icon. The speed of the interaction has an effect to this. Here are few citations from users (translated from Finnish):

"*Help! It clicked from the edge of the icon. I do not like that it does something before I do!*"

“It kind of clicks in the beginning and in the end, confirms. It feels like it is upraised and it clicks nicely“

“I liked the previous one even though it felt heavier than this one (Drag&Drop simple). It feels that it is quicker to do the tasks with this one.”

Hit special design consisted of three different feedbacks performed in pick and hit actions. Pick remained the same, but the hit feedback differed between targets (green square and blue triangle). Hit special design divided user opinions even more than Hit simple design. About half of the users commented that the different feedbacks between square and triangle were useful and pleasant. Sequential feedback with square hit action was described as “creak”, “buzz of a bee” and “purr of a cat”. It was also valued more pleasant than the double pulse feedback from triangle hit action. Four of the users didn’t comment the difference between hit feedbacks and two of the users commented straight that they didn’t feel any difference. Two of the users mentioned the sight as a first feedback channel and didn’t consider the haptic feedback equally important. Two of the users didn’t understand the idea of having different feedbacks in triangle and square, but some of the users invented use cases where this kind of functionality could be useful (translated from Finnish):

“Would be useful if there are two different selections side by side and the feedback would differentiate these two, you would not need to watch the screen.”

“It feels that it goes inside (green square)”

In **Drag&Drop none design** the same pick and drag feedback was planned to be used throughout the tests, but as mentioned before, it was noticed that the Drag&Drop none design differed from other designs (See Table 4). Continuous feedback while dragging divided user opinions. Five out of fourteen users mentioned that they do not like the feedback while dragging, whereas three out of fourteen users mentioned that they like the same feedback. One of the users mentioned the difference to other drag feedbacks and more than three of the users used word “bucket” when describing the drag feedback. Five of the users mentioned that they would like to have the hit feedback. Interesting comments were: “*I would like to go faster when I get this drag feedback*” and “*This feels slower when I have the drag feedback*”.

Drag&Drop simple design consisted of three different feedbacks: pick, drag and drop. Users who tried the Drag&Drop simple design after Drag&Drop none design commented the drag feedback to be better and more pleasant in Drag&Drop simple desgin. Only one out of fourteen users mentioned clearly that did not like the feedback at all in this design and one of the users commented that the feedback during drag did not feel natural. Four of the users were missing the hit feedback and valued the hit feedback to be more useful than drop feedback. However, three of the users liked the drop feedback as a confirmation of the task they were doing.

Interesting was that some users described that they felt different feedback when they were on top of the icon: *"Dragging feels like I roll the ball on the screen and hitting like throwing darts"*. This might tell about difficulty to separate the drag and drop feedback from each other and a good question is, do they need to be experienced as separate ones?

Drag&Drop special design consisted of the same pick and drag feedback as the previous design, but differed in drop feedbacks. Four out of fourteen users mentioned that they like the drop feedback with blue triangle, but not with green square. Three of the users described the double pulse triangle feedback to be easier to distinguish from the drag feedback than the sequential pulse feedback on square. One user even stated that the triangle feedback was perfect. Three of the users commented that they would like to have the hit feedback. One of the users wanted to have both hit and drop feedback. Drag feedback was mentioned negatively in two comments, but was also mentioned as the best design attribute in one comment. Most of the users did not comment if they would like the drag or not, but were just describing it and inventing use cases for it (translated from Finnish):

"It is good when you feel something. It feels like a heartbeat."
"I would like this drag feedback in some game. I could play it when I am bored for example when waiting for a bus."

One of the users commented that if having a drag feedback in device, there should be possibility to switch it off somehow. In general, the diversity of the user comments shows that the ***adjustability of tactile feedback*** can be seen as a one of the most important design principles when designing tactile feedback.

4.3. Post-test Interview comments

When interviewing the users it was seen that when the tactile feedback design got more complex, the variation of the opinions also increased. This can be explained with the individual differences in sensitivity of touch, different user expectations and with the simplicity of the test task. Users who had more experience with touch devices and tactile feedback commented that the feedback was not so effective because the test tasks were so simple and did not need so much concentration. This supports the importance of the ***meaningful combinations with different feedback channels.*** In addition to simplicity comments there were also other senses mentioned in user comments. Half of the users mentioned that they missed audio feedback as a support when doing the tasks, also the need of graphical support was mentioned. This confirms the assumption that ***the usage of multiple senses is more natural to user and different output methods should be designed together, as a complementary.***

The difference between simple and special hit or drop feedback were not commented clearly by users. Hit simple design, which were seen most light, useful and logical design had the same feedback when hitting the square or triangle. However, Hit special design which had the different feedbacks when hitting the square or triangle, were rated more pleasant than Hit simple. One user comment was *"it would be useful if I have two different options close to each other, so I would know that they are different from the different feedbacks"* whereas other comment was that *"I do not understand why they need to be different".* This advocates ***the importance of the meaningful design metaphors*** when adding the tactile feedback to the interface.

There were also comments which show how users experience some effects. For example the special hit effect on top of the square was described good or more personally as a purr. This shows how personal experience of different tactile feedback can vary and how ***important it is to make the feedback not only adjustable, but also context-specific***. More research needs to be done to test different kind of feedback combinations in Drag and Drop contexts.

4.4. Final interview

After all the task rounds there were final interview, where users could freely tell which feedback types they liked. Twelve of fourteen users mentioned the hit feedback when the favorite feedback experience was asked. Two of the users highlighted the difference of the hit feedbacks depending on the hit target. Three of the users were describing the favorite hit feedback with the sentence "The one which suck in the item". Pick was mentioned in nine comments, and it was also commented very useful during the tests. Drag was mentioned seven times, but four of them added that the drag feedback should be lighter. Only four users mentioned drop feedback. The combination of drag and drop feedback might have an effect to the few mentions of drop feedback as it was not clearly recognized by users. That is why drop should also be tested without drag and with hit feedback.

4.5. Comparing results to hypotheses

Three general objectives were given in the beginning of the test: Do users find a simple haptic design more pleasant and useful than a complex one in drag and drop context? Do users like to have feedback during a drag event? And what are the key events where to give feedback in drag and drop context? These three objectives were divided to five objectives and hypotheses which now can be answered according to the results:

1. Can user tell any difference between different hit feedbacks?
   Hypothesis: yes.

According to the user comments and interviews users could tell the difference between different hit feedbacks.

2. Which feedback type in hit situation is the most pleasant to the user?
   Hypothesis: Hit special design

According to the test results, Hit special design was seen the most pleasant design. However, the user comments in post-test interview shows that the simple hit feedback were most liked, so clear conclusion of which hit feedback was most liked is hard to give.

3. Does drag feedback have any influence to the user experience?
   Hypothesis: Yes. The assumption is that it disturbs the usage.

Originally the feeling in drag feedbacks were supposed to be similar, but accidentally Drag&Drop none design had different feedback, which had longer pulses during the dragging. Drag&Drop none design was rated lowest in every aspect: lightness, usefulness, pleasantness and logicalness. This mistake can be used when discussing the drag feedback and its influence to the user experience. Since the Drag&drop simple design was rated quite high in logicalness and Drag&Drop special design got also surprisingly high scores in every asked aspects, it can be concluded that the drag overall is not so disturbing place to give feedback that assumed. This finding was also supported in final interview, where users described the drag feedback useful. It was also mentioned that drag feedback should be very soft. According to these results, it cannot be stated that drag feedback would disturb the usage. It depends of the intensity of the continuous feedback and the user.

4. Do users find simple haptic design more pleasant and useful than a complex one?

Hypothesis: No. User finds a complex haptic design (Hit special and Drag&Drop special) more pleasant and useful.

The results show that the Hit special was rated the most pleasant design. This supports the hypothesis that users find more complex haptic design more pleasant. Also the good ratings given for the Drag&Drop special design support this. However, the Hit simple was seen more useful than Hit special, so definite conclusion cannot be made.

1. How do the users find the drop feedback?
   Hypothesis: users find the drop feedback useful.

Drop feedback was used in Drag&Drop simple and Drag&Drop special designs with drag feedback. Four users mentioned the drop feedback in their favorite combination of tactile feedbacks. One user commented when testing the Drag&drop special design that there should be some feedback when dropping the item. This shows that the drop feedback was not so clearly recognized with drag feedback and that it is why it is difficult to say if the users find the drop useful or not.

4.6. Comparing the results to earlier studies

Earlier studies related to drag and drop context introduced in this thesis were made by Poupyrev and Maryama [2003], and Tähkäpää and Raisamo [2002]. Poupyrev and Maryama studied that hit was seen most effective feedback place in lists and scrollbar to indicate the item scroll. Tähkäpää and Raisamo studied drag and drop context with haptic mouse and found that most liked feedback was when user was on the target. These same findings are supported by this study. Designs which had hit feedback were thought more pleasant than the ones without. The hit feedback in this study was given when the user was *in the edge* of the target but still some of the users commented that they get the feedback *on top* of the target. However, an important finding is that ***the indication when dragging on top of the target was seen useful and logical***. Interesting question is, if it really matters from the user point of view, if the edge of the target gives the feedback or should the feedback be given when the user is on top of the target. Some of the user comments show that it is important, but answering how -question is not possible at this point. More research needs to be done to solve if the hit feedback or on top –feedback is more relevant and what kind of feedback would be the best in these cases. It would be also interesting to find out how the effect design affects to the user assumption where the effect is triggered.

Poupyrev and Maruyama [2003] also observed that tactile feedback was effective in interacting with small components. User comments related to hit feedbacks was that *“it* *is easier to know when I am on the target"* and *"this kind of feedback would be very useful if I would have many targets on the screen"*. Two of the users also mentioned that even though the graphical indication is enough, it is good to have the feedback when the items are so small that it is hard to see them, or when the finger covers the whole item. The effectiveness of the tactile feedback when interacting with small components was also supported in pick feedback comments. Even though pick was not key objective in this study, users gave feedback of its usefulness. It was seen as an important indication when the red ball was picked.

4.7. Implications to haptic design

When thinking about drag and drop haptic designs there are different aspects to be taken into consideration. One thing is ***the drag and drop functionality***. The drag and drop can be done in desktop environment, where are objects and targets, but it can also be done in a context where user can pick the object and drag it freely around the screen or between multiple screens until dropping it somewhere. There are different actions that drop can do, for example user can drop the item inside the target like in the green square case or open something like in the blue triangle case. In addition, it can delete the item, change the position of all of the items on the screen or just change the placement of the object. So the use case of each drag and drop situation has to be considered separately. After finding out the functionality of wanted drag and drop situation the haptic design can begin.

According to the test results presented in this thesis, light guideline when designing tactile feedback to drag and drop mode, can be given. ***Pick and hit feedbacks were seen most important in drag and drop mode***, ***so they should be the minimum feedback experience offered to the users***. Pick is usable feedback no matter what is the functionality. It always indicates the user interacting with the object that it is successfully picked and next possible action can be made. The need of hit feedback can vary between functionalities. For example in use case where the item can be dragged over multiple screens, should the hit feedback be given when the user crosses the edge of each screen? Or should the hit feedback vary if user drags the item on top of the wastebasket where item can be deleted by dropping it, compared to the folder hit feedback? It should be also considered *where* to give hit feedback: when the user hits the edge of the target or on top of the target. This can also be considered via use case: should the wastebasket give continuous feedback when user is on top of the bin with item to indicate that drop will delete the item? Also the variation and amount of different hit feedbacks should be tested with actual drag and drop use cases to find out what kind of hit feedback would be most useful and pleasant from user point of view.

Drag feedback divided opinions in this study, but was not seen unpleasant or even illogical, which can be seen in Drag&Drop special design results. ***Dragging feedback should be considered very closely when designing tactile feedback***. Even though the intensity level can be very small and feeling of the effect smooth and sensitive, the constant feedback can be annoying in the long term use. That is why the design should be also though via use case (is it something that is in use all the time, does it have major benefit to user?) and tested in a long term.

The importance of the drop feedback was not clearly shown in this study as it was used with drag feedback. Drop feedback could be used with hit feedback, but new test setup should be arranged to find out more from this combination. Drop can be sometimes more usable than hit feedback depending on the functionality. For example, screen where only two movable items are arranged freely on the screen, the drop feedback would be better to indicate that the user has dropped the item on a new place. Or if the screen is full of items, would it be beneficial to give hit feedback from each item or only drop feedback when user finds a new placement to the movable item?

Like discussed earlier in this thesis the technical decisions has impact to the haptic design. The design limitations changes whether we use vibra actuator or piezo technology, and capacitive or resistive display. Also the graphical user interface has impact to it with its touch event trigger points, graphical elements and other output methods used in the device. One important fact is to think about the user settings for tactile feedback. The results in this study showed that the tactile feedback evokes opinions and emotions, which vary between users. Touch sensation is something we all have, but it is experienced differently by all of us. Noisy situations, age, touch sensitivity and even cultural difference affects to the pleasantness level of the intensity in tactile feedback. That is why more than one level should be offered to the user. Simplicity is one key question in user interface design why complex settings are not recommendable, but in case of tactile feedback, the variation of different settings should be considered. For example the drag feedback could be something that user might want to adjust by themselves or switch off totally.

Another key question when designing tactile feedback is other feedback modalities. Audio and graphical feedbacks were mentioned couple of times during the tests. It is natural to experience the world with multiple senses and that is why using the tactile feedback alone can be poor solution for interface design. Different modalities support each other and the best benefit can be achieved if they are designed together as a consistent feedback system.

The role of the tactile grows in situation where user has disabilities like deaf users, but also in situations where the cognitive load is high. The design space introduced by Poupyrev et al. (2002) describes this cognitive load as another variable giving an example of situation where user needs to walk or run at the same time when interacting with the device. The other variable is the abstractness which should be taken into account when designing the tactile effects. For example, the feedback for drag and drop situation can be from real life metaphor of opening the door: first user unlocks the door (pick), then opens it (drag) until it hits the maximum point (hit) and then locks it again (drop) or just abstract effects indicating the actions.

The results shown in this thesis gives some basics to the tactile feedback design in drag and drop situation. Further study will open more detailed design principles as well as more knowledge of the different aspects affecting to the design. One thing we can be sure of is that ***the design work should always start form the user's needs.***

5. Summary

The results of this study showed that the design of tactile feedback has statistical significance in drag and drop context. Tactile feedback is not only useful and logical way to inform the user of the interaction with touch screen device, but it also creates opinions and feelings. User comments such as *”I hate that it vibrates all the time*” and ”*I like that purr it gives me”* illustrate how different experiences and strong associations we can have via tactile feedback.

Based on this study, the hit feedback was seen most logical and useful place to add tactile feedback. However, other combinations should be studied, for example different hit feedbacks where there are many targets, different drag feedback with hit feedback and drop feedback without drag feedback. Also combinations of different modalities should be tested, where audio, graphical and tactual perceptions are thought as one feedback system. The task rates could be compared to the earlier studies where only one or two modalities have been used.

It was observed in the study that age has an effect to the sensitivity of the touch sense. Although statistically small group, two elder users commented that the feedback should be louder and other one tried to hear the feedback even though the headphones were used. That supports the assumption that when getting older, the support of multiple senses is more important. This could be researched further by comparing two systems with and without multiple feedback methods. It would be also interesting to compare a group of young users to elder user group to distinguish how much the sensitivity of touch sense changes with age.

In the future research the comparison of the different tactile feedbacks should be taken into closer examination. It was clearly observed that when users had something to compare with, it was easier to rate the different designs and feedbacks. There could be two different user groups in comparison, where other one consists of users who have already used touch screen mobile devices with tactile feedback, and another where users have not used tactile feedback devices. That could give some kind of understanding how the familiarity of tactile feedback affects the opinions and usage.

One interesting observation from this study was the user recognition of the hit feedback. Some of the users thought that hit was given on top of the target, when some recognized that it was given at the edge of the target. The pattern of a feedback could influence this phenomenon as the longer special hit feedback with multiple pulses were described as a purr on top of the item, even though it was given at the edge of the target. It would be interesting to test, how users would like if the purr would be given on top of the target, as long as the touch is held down on top of it and what happens with fast drag, when multiple targets are passed (hit) in a short time frame.

As this study only scratched the surface of the Drag and Drop context haptic design, there are plenty of research topics for the future. More research is needed to create guidelines for tactile feedback design in touch screen hand-held devices and more pleasantness studies is needed to get user opinions of these designs.

“Good design will have it all – aesthetic pleasure, art, creativity – and at the same time be usable, workable, and enjoyable” *Donald Norman, The design of everyday things*

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Appendix 1: Pre-test questionnaire and user data form (Finnish)

<table>
<tr><th colspan="3">BACKGROUND INFORMATION</th></tr>
<tr><td>Käyttäjänumero:</td><td colspan="2">Päivämäärä:</td></tr>
<tr><td colspan="2">Nimi:</td><td>Sukupuoli:</td></tr>
<tr><td>Ikä:</td><td colspan="2">Ammatti/Pääaine:</td></tr>
<tr><td colspan="3">Mikä on tämänhetkinen puhelimesi? Kuinka kauan se on ollut käytössäsi?</td></tr>
<tr><td colspan="3">Oletko koskaan kokeillut kosketusnäyttölaitteita? Jos olet, niin mitä ja missä?</td></tr>
<tr><td colspan="3">Oletko koskaan kuullut tuntopalautteesta laitteissa? Tiedätkö mitä se tarkoittaa?</td></tr>
<tr><td colspan="3">Oletko koskan kokeillut laitetta jossa on tuntopalaute?</td></tr>
</table>

Appendix 2: Pre-test questionnaire and user data table (English)

User	Gender	Age	Touch screen usage	Have you ever heard about tactile feedback? Do you know what it means?	Have you ever used any device with tactile feedback before?
1	Male	39	Yes, several Nokia mobile phones, touch screen devices etc.	Yes.	Yes.
2	Female	34	No	Alert vibra in mobile device	No
3	Male	25	Yes, Nokia 5800Xpress music phone	Yes, I feel when I have touched.	Own phone Nokia 5800 Xpress
4	Male	25	Navigator	No idea.	No
5	Female	56	Copying machine	I have heard.	No
6	Male	55	Control panel in hydraulic platform	No. Somekind of punch when you touch. Good for blind.	No
7	Male	29	Copying machine, Nokia 5800Xpress Music Phone, Nokia N97, touch pad tablet	Yes. Feedback to user interaction.	Yes. Nokia 5800Xpress Music Phone, Nokia N97
8	Female	27	Induction cooker, refuelling device	Yes. When you press, you get something.	No.
9	Female	26	Nokia 5800Xpress Music Phone, PhotoPlay	No. Maybe it is something that how it reacts to your touch?	No.
10	Female	25	PhotoPlay, Nokia 5800Xpress Music Phone, fingerprint recognizer	No. Maybe it gives some feeling back to my finger.	Do not recall.
11	Female	29	PhotoPlay, Nokia 5800 Xpress Music Phone, Samsung	Yes. My phone has it	Yes. Samsung U700

			U700		
12	Male	25	Nokia 5800 Xpress Music Phone, touch screen computer, PhotoPlay, Refuelling device	Yes. It vibrates when it recognize my touch.	Yes. Own device Nokia 5800 Xpress
13	Female	23	PhotoPlay, Touch Screen computer,	No. Some vibrating thing?	No.
14	Male	32	iPod, iPhone, google phone	Yes. You get feedback so you feel it, stimulus to skin, so you do not need to see it.	Yes. Playstation controller.

Appendix 3: Post test interview (Finnish)

Käyttäjä #: Päivämäärä: Testitehtävät:

Törmäys ja tiputus palautteiden testien haastattelukysymykset

Palautteet tuntuivat

Raskailta	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**Kevyiltä**

Palautteet tuntuivat

Epä-miellyttävilt ä	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**Miellyttävilt ä**

Palautteet tuntuivat

Hyödyttömiltä	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**Hyödyllisiltä**

Palautteet tuntuivat

Epä-loogisilta	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**Loogisilta**

Auttoiko tuntopalaute suorittamaan tehtävän?

Tunsitko eroja palautteiden välillä?

Mikä on mielestäsi miellyttävin palautekokemus?

Olisiko tämän tapainen palaute mielestäsi hyödyllinen raahaa ja pudota (drag and drop) tilanteissa?

Appendix 4: Final interview (Finnish)

1. **Mitkä ovat ensimmäiset ajatuksesi testin jälkeen? Miltä laitteiden käyttäminen tuntui?**

2. **Mikä oli erityisesti hyvää? Mitä pitää parantaa?**

3. **Mitä ajattelet yleisesti tuntopalautteen antamisesta kosketuslaitteella?**

4. **Jäikö jotain erityisesti mieleesi tuntopalautteen suhteen testeistä?**

Appendix 5: Check list for moderator (Finnish)

- Testi on vapaaehtoinen ja sen voi jättää kesken koska tahansa
- Testissä testataan laitetta eikä käyttäjää
- Ääneen ajattelu
- Läpikäynti laitteesta: miten pitää kiinni, styluksen tai kynnen käyttö
- Kerro että testitehtäviä on kolme, jotka toistetaan kuusi kertaa
- Kuulokkeiden käyttö
- Kyseessä tuntopalaute tutkimus jonka takia tulisi keskittyä aistittavaan tuntopalautteeseen
- Tehtävien suorittaminen itse loppuun asti ja aloitus alusta jos ei onnistu
- Neuvo ikoneiden keskelle osumisesta epäselvän kosketusalan vuoksi