

Designing Haptic Clues for Touchscreen Kiosks

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Most interactive touchscreen kiosks are a challenge to accessibility: if graphics and sound fail in communication, the interaction process halts. In such a case, turning to the only remaining environmentally suited sense – the touch – is an intuitive option.

To reinforce the interaction with interactive touchscreen kiosks it is possible to add haptic (touchable) feedback into the features of the device. The range of touchscreen-suited haptic technologies already enables some touch feedback from touchscreen surfaces and significant leaps still forward are being made at a constant rate. Due to this development it is relevant to review the human-centred factors affecting the design of haptic touchscreen in public kiosks.

This thesis offers an overview for designing haptic clues for touchscreen kiosks. It emphasizes context sensitivity and the meaningfulness and communicability of different haptic design variants. As the main contribution, this thesis collects together the important considerations for the conscious design of haptic features in interactive kiosks and offers points of multimodal design considerations for designers intending to enrich their touchscreen interaction with haptic features.

Key words: haptic touchscreens, interactive kiosks, haptic senses, haptic design theory.

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1 INTRODUCTION

This thesis takes a look at haptic interaction as a complementing modality with graphical user interfaces in touchscreen kiosks and vending machines. The theme was inspired by the recent development of touchscreen devices in public environments, and evaluated to be topical, due to the increasing demands for accessibility. The content consists of haptic perception related observations, explanations of haptic technologies, and discussions about design approaches for applying haptic variables.

1.1 Field of study

Touchscreen interfaces are increasingly popular and common in public environments. They can be found, for example in all types of self-service ticket and information kiosks and vending machines at stations, airports, hospitals and shopping malls; and even at self-checkouts at stores and libraries. The emergence of touchscreen interfaces has given self-service devices a better coverage in available actions and a great potential for improving user-device interaction. With these qualities public touchscreen devices offer benefits for the majority of users in everyday basis.

From a design point of view, the genius of touchscreen user interfaces lies in combining the input and output elements [Hoggan et al. 2008]. A single solid surface of interaction enables flexible and efficient layouts for the graphically presented control items. The adaptability, intuitiveness and potential for communicative and elaborate information presentation promote usability in effective ways. With physical switches, buttons, sliders and knobs this has never been possible to the same extent. Therefore, the change of the interaction system from buttons to touchscreens is well justified.

However, even with all of its advances, touchscreen devices have not yet reached some of the natural characteristics of conventional switches: the perceptions beyond eyesight. Public touchscreen devices rely significantly on the graphics of the interface and therefore, if the user's vision is compromised, the use of the device becomes difficult or even impossible. This is a major issue decreasing and delimiting the possibilities of independent actions for the visually impaired. An interface relying solely on a graphical screen is an accessibility problem.

In interfaces with physical switches, visual, auditory and haptic characteristics have always been inseparable. In physical interfaces, each of these characteristics is usually carefully planned and controlled to support a specific experience and notion of function.

These multimodal interfaces, with their distinct features for touch and hearing, have been serving also those with limited abilities. The use of haptic and sound design in physical interfaces has in fact been so successful for non-visual accessibility, that certain touchable and hearable features have become internationally recognized and standardized in the interfaces of public devices.

Now as the inherently multimodal, physical user interfaces are being replaced by touchscreens, it is relevant to question if and how the new technology can meet the existing standards for user needs. While integration of audio has already been widely explored, proven useful and utilized in most touchscreen interfaces, the touchable (haptic) features appear to be more ambiguous to design and execute.

1.2 Research questions and aims

“Designing for meaningful tactile communication should be guided by a broad and integrated knowledge of how tactile information is encoded, transmitted, and processed at various stages of a tactile interaction.” [Pasquero, 2006]

In a pursuit of better usability, accessibility and pleasant user experiences for self-service devices in public environments, this thesis aims to clarify the factors related to haptic features in touchscreen kiosks. The initial research questions to answer are:

- (1) How could touchscreen kiosks utilize haptic sensations to better include visually impaired users?
- (2) What would be required for touchscreen kiosks to communicate through haptic sensations?

Guided by the quotation by Pasquero [2006], this thesis takes a look at the three different aspects of haptic interactions: the factors of processing, transmitting and encoding meanings.

1.3 Partnership

This thesis has been done in cooperation with KONE Oyj. As a major player in innovating, developing and producing solutions for enabling indoor-traffic through

elevators, escalators and automatic doors, KONE is an excellent example of a company the decision of which in interface design affect millions of end-users globally. As a service producer they are also responsible for ensuring safe and accessible interaction and passage to all of their users.

This thesis aims to offer an overview on the design factors of interactive touchscreen kiosks for the future development of KONE products.

1.4 Approach and structure

This thesis starts by describing the complexity of touchscreen use-cases in public environments in Chapter 2. Different aspects of haptic interfaces are then discussed according to a division adapted from Pasquero [2006]: in Chapter 3 I summarize aspects of haptic perception from the point of view of touch-sense processing; in Chapter 4 I continue by discussing about matters of touch transmittance, a.k.a. haptic interfaces, and finally, in Chapter 5 I collect findings and thoughts on the systems of encoding haptic messaging and makes notations on the effects of design. In Chapter 6 I evaluate the potential and usefulness of the previously presented theory for haptic design.

This thesis takes a designer approach on the topic by presenting important background information, synthesizing earlier research findings and presenting practical observations. Applications of the discussed design theory are considered hypothetically, but practical experiments are left for future work.

2 DESIGN FRAMEWORK OUTLINED

The design of touchscreen interfaces in public environments concern a wide variety of topics. The challenges for design have to do with the many user stakeholders, varying environmental contexts and the tailoring of the physical and technical device to match at least the most common requirements. In this chapter I present some of the context associated factors that set limitations and guidelines for haptic design in public touchscreen devices.

2.1 Design of interactive kiosks – challenges of common use

An interactive kiosk (IK) is a self-service device, usually fixed into a public space for common use. These devices are often used in service tasks that concern information processing, such as buying a train ticket, taking money out from a cash machine and registering bought groceries and paying for them at a store (Figure 1). The popularity of these kiosks can be explained mainly by two factors: savings on service-personnel costs and improved availability of services in terms of location and service hours [Maguire, 1999].

In many aspects interactive kiosks are demanding devices to design. Interactive kiosks concern a potentially large variety of segments with many types of user needs. To ensure usability, interactive kiosks have to be self-explanatory due to the fact that they usually stand alone with no human-personnel for assistance. Another significant design challenge is the interactive kiosk's applicability to the settings of the task; what the device is used for, where it is located, at what time of the day it is used, and how it needs to be maintained are just some of those topical issues [Pasquero, 2006]. In short, in order to be approachable and functional, the design of the kiosk has to respond to the requirements of the multitude of users, tasks and environments.



Figure 1. Examples of touchscreen kiosks: (1) train ticket vending machine, (2) information screen in a shopping mall, (3) library lending kiosk, (4) check-in at a healthcare centre, (5) photo printing kiosk, (6) photo booth, (7) coffee vending machine, (8) slot machine, and (9) post package kiosk.

Interactive kiosk device design cannot be approached with a narrow scope. The challenges and requirements relating to interactive kiosk design have been discussed in some case studies and few general design reviews. *A review of user-interface design guidelines for public information kiosk systems*, an old paper by Maguire [1999] gives a

long list of recommendations for design, discussing all aspects of design from the graphical features to interaction modalities and even the placement of the device. The same kind of holism in design is considered through other design studies concerning interactive kiosks [Günay and Erbuğ, 2015; Sandnes et al. 2010].

Maguire [1998] identifies *effective use*, *inclusiveness* and *supportiveness* as the main motivations of IK design, but in more recent material [Günay and Erbuğ, 2015] the objectives seem to have shifted towards enhancing user *experiences* and *emotions*. To maximize usability and to avoid negative user experiences, designers look to the design principles, heuristics and recommendations of Donald Norman, Jacob Nielsen and Ben Shneiderman, the thoughts of whom are especially beneficial in the context of non-expert users. In addition, the more recent research and product development in the field of interactive kiosks and public service UIs have given new, additional definitions for “good design” [Siebenhandl et al. 2013; Sandnes et al. 2010]. When a requirement listing (Figure 2) is collected from the notes of Maguire [1999], Siebenhandl et al. [2013] and Sandnes et al. [2010] the emphasis appears to be on the aspects of communicability and environmental context.

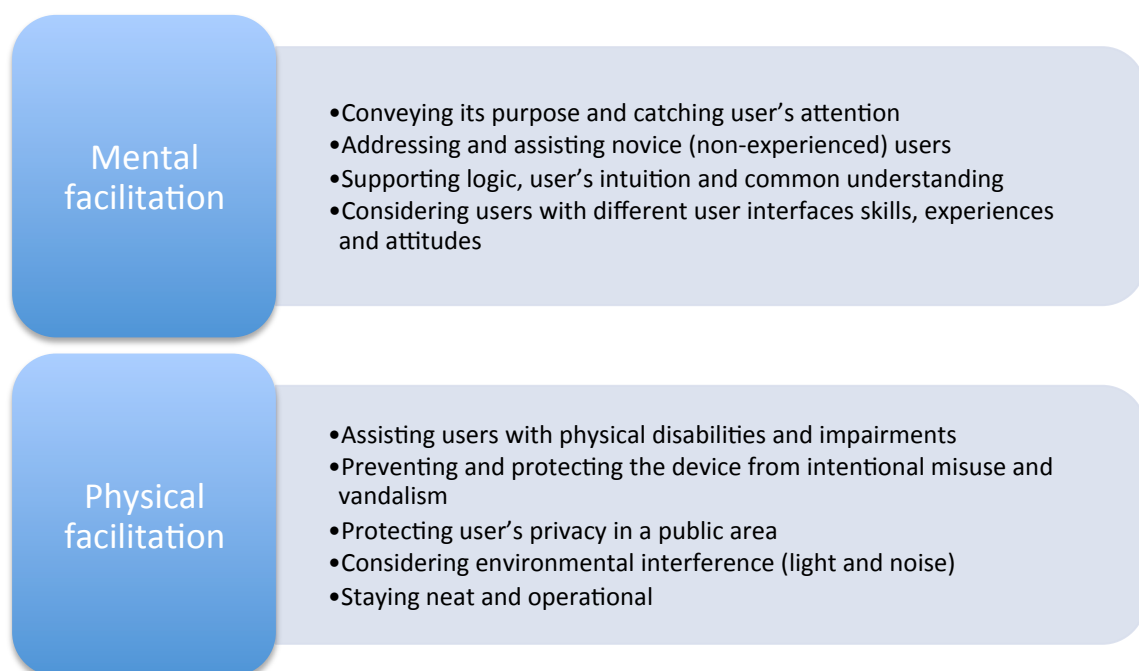


Figure 2. Considerations and requirements for successful interactive kiosk design applied from the notes by Maguire [1999], Siebenhandl et al. [2013] and Sandnes et al. [2010].

Like other user interface design cases, also the design of interactive kiosks overlaps with different design disciplines. To motivate the existence of the interactive kiosk,

service design defines the existing needs, possible challenges and future service potential for each stakeholder. In this process it is advised to conceptualize possible task and operating environment scenarios [Maguire, 1999]. When the content of the service is clear, information architecture and communication design offer tools for sorting and presenting the features. Both the navigation and the presentation of information should follow a logical, task-oriented; alphabetically or temporally order system [Maguire, 1999]. The industrial/product, hardware and software design should enable flexibility for many reasons. The device is likely to have different types of users, the service offering might change and the user interface features might require adaptations over time. How the user feels comfortable interacting with the device and what arising experiences are, are defined with focuses on interaction and user experience design. The ergonomics of the usability and much of the non-verbal communication is added through graphic design and industrial/product design.

2.2 Accessibility and interactive touchscreen kiosks

Accessibility is a characteristic referring to the qualities of being accessible, approachable, usable and obtainable [Merriam-Webster, 2014a]. It is an essential attribute in all design and as such, it can be defined as the availability of services, enabled use of tools, clarity of information and ability to participate in decisions concerning oneself [Invalidiliitto, 2014]. Traditionally in dictionaries such as the Merriam-Webster, disability is defined as a condition damaging or limiting the physical or mental abilities, often relating to an illness or an injury; and in a complementary vignette, referred to as the inability to “do things in the normal way” [Merriam-Webster, 2014, b]. The WHO’s International Classification of Functioning, Disability and Health (ICF) represents a more modern and holistic view by explaining disability as “*a result of an interaction between a person (with a health condition) and that person’s contextual factors (environmental factors and personal factors)*” [ICF, 2014].

The availability of services and information links accessibility essentially to information technology. Amongst the users of technology, there is a large diversity in the physical and cognitive abilities and disabilities [Hagen and Sandnes, 2010]. These varying user needs are addressed as issues of accessibility design (also referred to as universal or inclusive design) and considered in the design of interactive kiosks by international standards (ISO) and accessibility goals set by United Nations [UN, 2007]. Though the current trend is to produce accessible design by giving special attention to disabilities, from a design perspective, the ICF description offers a challenging viewpoint: the

design focus should maybe not be in the user's inability, but in the possibilities of enabling different types of abilities.

Poorly designed touchscreen devices can compromise the interaction's success for a wide range of users. These individuals include people with visual, auditory, motor, cognitive and seizure disabilities and disorders. [WHO, 2014] This is a significant problem especially with publically places interactive kiosks since services in certain locations and situations depend on them.

The interfaces of interactive kiosks have typically been relying on either single buttons or series of organized buttons (a number pad or a keypad) with a separate screen, but recently an increasing number of interactive kiosks use a touchscreen for both output and input. The lack of physical controls gives the system a new freedom to present information in an adaptive way, but at the same time the presentation has become much more dependent on graphics. This beholds a major problem for accessibility and general usability: the intuitive sense of object manipulation and spatiality perceived through touch is lost.

In touchscreen interaction, visual dependency is a major problem for accessibility. The size of objects and impractical placement of the interface panel are both causing difficulties in seeing and reaching [Hagen and Sandnes, 2010]. Other typical problems for user interface accessibility with those public devices are: insufficient contrast on the screen, brightness or use of disturbing light effects; difficulties in targeting and hitting the graphical buttons; and weakened cognitive abilities, that may complicate perceptual interpretations and limit the understanding of the interaction process and interface contents. The single largest user group with reduced abilities is the elderly. With age the likelihood of the aforementioned conditions increase while the dependency on assistive technology is likely to increase significantly. [Hagen and Sandnes, 2010]

Regardless of the age of the user and his/her condition sometimes even users within a "normal range of abilities" can struggle with interactive touchscreen kiosks. The environment can make the interaction challenging, if the senses of sight and hearing are disturbed. In those situations, the supporting or optional modalities prove their usefulness, though in many current systems extra modalities are not included.

As universally touchscreen technology has been noted to behold a particularly adverse problem for the millions of visually impaired people in the western world alone, the blind and the visually disabled are a major focus group for accessible touchscreen design. For them, the two senses to rely on in interaction are hearing and feeling through touch.

“Visual disability is a form of information disability.”

- Teuvo Heikkonen [Näkövammaliitto, 2015]

A visual impairment refers to a defected ability to perceive through eyesight. There are different types and levels of visual disabilities, but most commonly visual impairments can be divided into three categories: blindness, low vision and color-blindness [Webaim, 2013]. Each type of visual impairment requires a different approach in inclusive design. It is important to recognize that while issues of color-blindness and low vision might be sufficiently eased by good GUI design, design for blindness demands an approach beyond the visual modality.

“...the increasing use of touchscreen technology presents significant problems to the European Union’s 2.7 million blind and 27 million visually impaired citizens.”

[McGookin et al. 2008]

Electronic services for information, communication and emergencies are mentioned in detail as some of the likely barriers to accessibility [UN, 2007]. Public devices relying on graphical user interfaces, such as self-service kiosks, info screens and ATMs, are especially common in those particular service tasks.

To better include the non-seeing users, some devices offer sound as an alternative modality for interaction. However, locating the device and its controls, determining if it is functional and catching and understanding the sounds remarking actions is still a major challenge [Cassidy et al. 2013]. The defecting factors for the perceptibility, such as environmental noises, the user’s defected hearing, linguistic features, overhearing ears, and the temporal quality of sound messages, make auditory output challenging to utilize in publically placed devices. Some of the mentioned issues have been taken into consideration by adding a headphone attachment, but the pre-read interface is slow and bulky and still far from matching the efficiency of the graphical user interface it is made to model. Cassidy et al. [2013] also noted that the use of headphones makes the user more vulnerable because the environmental sounds cannot be heard so well and because to a possible attacker headphones are a signal of the user’s unawareness of the environment.

“Whilst a visually impaired person can learn the locations and functions of tactile control panels on current mobile telephones and public access terminals, attempting to do the same with touchscreen based devices is much harder, due to the lack of tactile distinguishment between virtual buttons and surrounding surfaces.” [McGookin et al. 2008]

While some of the mentioned problems of navigating to the device and within the user interface have been fairly tolerable with physical interfaces, touchscreens have proven to be an insuperable obstacle to blind users.

2.3 Summary of the design framework

Interactive kiosks are self-service devices usually located in public areas. Their major benefit is in facilitating services without personnel at site. Interactive kiosks behold a wide range of design challenges. Due to their common use in public spaces, they are required to be communicative and accessible regardless of the environment, user’s abilities and the task they facilitate. In current design the requirements are not just effective use, inclusiveness and supportiveness, but also non-negative user experiences. In greater detail, interactive kiosks are supposed to be easily approachable; to attract, address and assist especially novice users. They should support intuitive and logical behaviour while enabling interaction and securing the process for the abled and disabled alike. In addition, they are required to stay neat and functional also when not surveilled.

Information technology is responsible for the availability of services and information in an increasing extent. Therefore, the role of accessibility as an attribute in all design cannot be overestimated. While traditionally the approach in inclusive design has been the overcoming the user’s inability, much and more can be discovered by supporting varying abilities through multimodal systems - systems that interact through more than just one sense simultaneously.

Putting effort into accessibility has become particularly important during the recent years, as it has become common for user interfaces in interactive kiosks to utilise touchscreen technology. The emerged problem is obvious to notice, though difficult to solve: interactive touchscreen kiosks are much too dependent on the user’s eyesight. The intuitive perceptions of spatiality and physical object manipulation are lost in

fingering a sheet of glass. While the haptic features do not offer assistance, the graphical user interfaces face challenges with seeing, targeting and hitting. The cognitive abilities of the user are also often put to the test, as the graphical presentations can present complex navigation tasks. These challenges are most common with the elderly, the abilities of whom can be significantly constricted by the increasing age, but demanding light and sound environments can hinder touchscreen usability even for a normally perceiving person.

However, as touchscreen technology has been noted to behold a particularly adverse problem for the millions of visually impaired people in the western world alone, the blind and the visually disabled are a major focus group for accessible touchscreen design. For them, the two senses to rely on in interaction are hearing and feeling through touch. In the context of interactive kiosks and public locations touch has the advantage of being a medium of private and subtle messages. Unlike sound, touch is often less dependent on time and better in communicating spatial dimensions and physical affordances. For the visually impaired, haptic sensations in user interfaces can be an effective channel for interaction.

3 HAPTIC PERCEPTION

Haptic perception is perhaps the most difficult perception to understand. To a healthy person it is such a vital part of existing that the richness of it easily goes unnoticed and acknowledged. In this chapter I discuss the physiological and perceptual aspects of haptic sensations in an effort to describe the complexity of touch. The following material consists of the basic knowledge required in order to understand the human counterpart in haptic interaction design.

3.1 The senses of touch

“Good design for tactile interaction should be guided by a minimum understanding of touch.” [Pasquero, 2006]

The word “haptic” is used when something relates, uses or is based on the sense of touch [Merriam-Webster, 2014c]. Haptic perception means the ability to feel through sensations on and in the body. Haptic feelings, which are often referred to as somatic (body-related) senses, are a combination of different senses, such as pressure, temperature, body posture and balance. All of these sensations come from signals that are sent through receptors located in skin layers, muscles, joints, bones and viscera. [Saladin, 2010]

Being the earliest sense to develop [Montagu, 1986], touch does not only give an awareness of what is going on within the body and mediate the qualities of physical objects, but most importantly: the sense of touch communicates about the body’s presence in the environment. The sense of touch gradually develops alongside other senses and contributes significantly to overall perceptual understanding [Hatwell et al. 2003] and control over motor functions [MacLean, 2008]. Haptic sensations are a part of the continuous flow of information consciously and unconsciously being monitored by the brain.

Haptic sensations are perceived through receptors that transmit signals to a sensory nerve and the brain. As with all sensory channels, the body registers the stimulus if its threshold is greater than that of the receiving receptor. Depending on the type of the

receptor and the stimulus the interaction can launch either an unconscious or a conscious sensation. If the sensation is perceived and processed consciously it creates a notion of a perception. The visualization of this process can be seen in Figure 3.

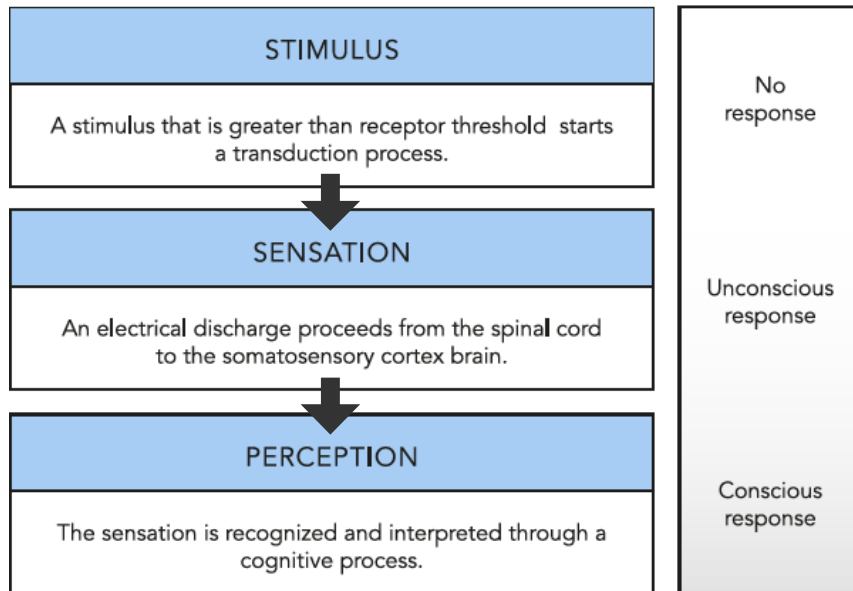


Figure 3. Three step somatosensory process.

The haptic receptors can be classified at least in three ways depending on the approach. Classifications can be made according to the distribution of receptors in the body [Saladin, 2010], the location of the receptor in the body or according to the transduction mechanism of the receptor [Raisamo and Rantala, 2016]. The presented classifications of the haptic receptors are mostly overlapping, but the characteristics of the presented classes are illustrative in explaining the complexity of haptic sensing.

According to the classification system of receptors' distribution in the body, which refers to the sensory modality, there are *general senses* and *special senses* (Figure 4). The general senses are those registering stimuli from receptors located through the body. General senses consist only of haptic senses, and likewise most haptic sensations are general senses. The only exception is the equilibrium (sense of balance), which registers stimulus solely within the head. Like the other special senses, such as vision, hearing, taste and smell, the sense of balance also utilizes – in comparison to haptic sensing – a more complex sensing system. [Saladin, 2010] This classification points out the significance of haptic perception in contrast to the other senses. It is a sense that is less dependent on cognition and quickest to develop in the efforts of learning to interact with the surrounding world [MacLean, 2008].

GENERAL SENSES	SPECIAL SENSES
Receptors distributed around the whole body	Receptors locating only within the head
...manifest themselves in the somatosensory system as...	
Sense of touch	Sense of balance
Sense of pain	
Sense of vibration	
Sense of temperature	
Sense of posture	
Sense of heart rate	
...	

Figure 4. Categorization of touch senses according to Saladin [2010].

When classified according to the transduction mechanism (stimulus modality) the differentiating feature is the receptor's reactivity to a specific type of stimulus. In the transduction mechanism based classification the different types of haptic receptors are the *thermoreceptors*, *nociceptors*, *chemoreceptors* and *mechanoreceptors* (Figure 5). Thermoceptors are located everywhere in the body from the skin to the spinal cord. They mediate sensations of temperatures and enable the thermoregulation of the body. Thermoceptors participate in both conscious and unconscious monitoring of temperatures. Nociceptors are almost everywhere in the body and they register feelings of noxious (tissue-damaging) stimuli, perceived as pain. Nociceptors purpose is to alert the awareness to a possibly hazardous condition. Chemoreceptors are mostly related to taste and smell, but in haptic sensing they also detect substances produced within the skin [Raisamo and Rantala, 2016]. Mechanoreceptors are located everywhere in the body. They sense feelings such as touch, pressure, vibration and skin stretch. Depending on the adaptation time to stimulus, they can be divided into three categories: rapidly adapting receptors, moderately rapidly adapting receptors and slowly adapting receptors. [MacLean, 2008; Raisamo and Rantala, 2016; Ward and Linden, 2013].







Illustration							
Receptor name	Pacinian corpuscles	Meissners endings	Hair receptors	Ruffini endings	Merkel's discs	Free nerve endings	
Receptor type	Mechano-receptor	Mechano-receptor		Mechano-receptor	Mechano-receptor	Nociceptors	Thermo-receptors
Stimulus type	Rapid vibration	"Taps", slow vibration		Skin stretch, movement of joints	Pressure	Pain	Temperature
Rate of adaptation	Very rapidly adapting	Moderately rapidly adapting	Moderately rapidly adapting	Slowly adapting	Slowly adapting	Depends on the stimulus and location	
Location in the skin	Deep	Shallow	Shallow	Deep	Shallow	Both shallow and deep	
Receptive field	>20 mm	3-5 mm		>10 mm	2-3 mm		
Frequency of stimulus	100-500 Hz	3-50 Hz		0-10 Hz	0-10 Hz	-	-

Figure 5. Receptors, their qualities and the different categorizations in contrast to each other. An adaptation from MacLean [2008], Raisamo and Rantala [2016] and Ward and Linden [2013].

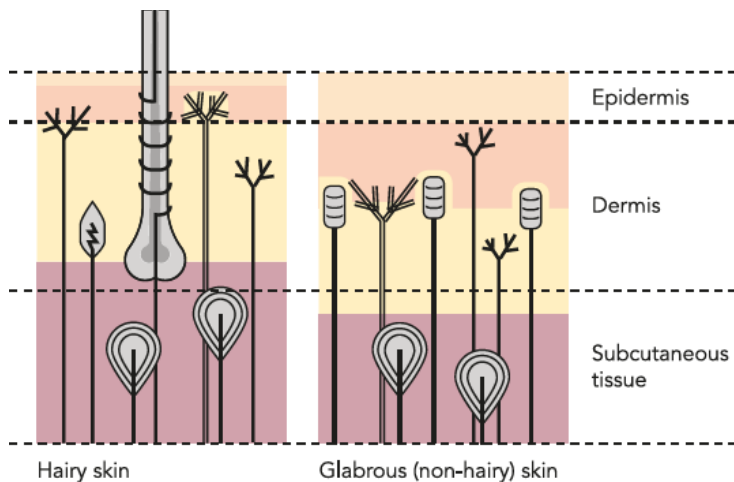


Figure 6. Receptors in hairy and non-hairy skin. Redrawn from an illustration by Raisamo and Rantala [2016].

According to the location-based classification (Figure 7), there are three receptor types: skin receptors, muscle / joint receptors and visceral receptors. *Skin receptors* (extroceptors or tactile/cutaneous receptors), which are presented in Figure 6, sense skin contact, such as pressure, temperature, pain, slip, vibration etc, which provide *tactile* sensations for example when investigating material properties [Hatwell et al. 2003].

Muscle and joint receptors (proprioceptors) communicate about the position, orientation and movement of the body and body parts in space [MacLean 2008]. It is also called the *kinesthetic sense*. *Visceral receptors* (interoceptors) are the monitoring receptors of inner-body sensations such as those coming from the organs and inner tissues. The internal sensations concern mostly automated body monitoring, such heart rate, bladder pressure, sense of balance and nausea [Saladin, 2010]. Introception can participate in the overall feeling and interpretation of the kinesthetic and tactile sensations for example in cases of hypertension or fever. However, as visceral sensations have a vital role in unconscious internal monitoring, they cannot be easily affected and utilized in the same way as the kinesthetic and tactile senses. Out of these sensing types the *kinesthetic* and the *tactile* sensations form the most important perceptions of the world around [Saladin, 2010].

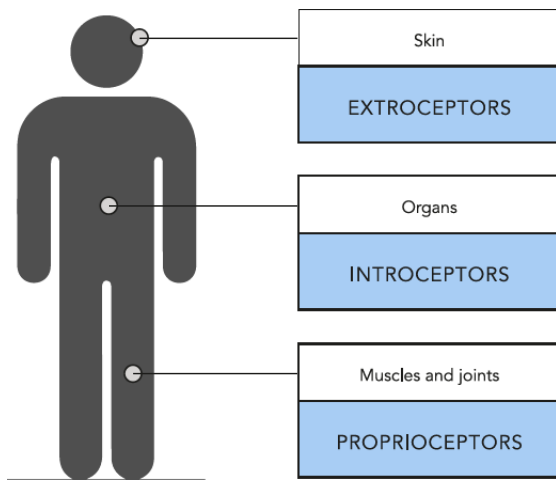


Figure 7. Categorization of receptors according to their location in the body. Applied from Saladin [2010].

3.2 Haptic sensation as an information channel

With a healthy person, the sense of touch is present at all times, though all sensations are not registered consciously. Most of the reactions to the haptic sensations, such as correcting body balance, gripping an object with the right force and pulling your hand away from a hot plate, also happen automatically. In addition to the intuitive use of the haptic sense, both the kinesthetic and the tactile perceptions can be fine-tuned to support very complex tasks, such as mastering a musical instrument, sport or reading by touch. As with any other sense, practice and exposure to varying haptic conditions develop the abilities to differentiate the fine nuances of stimuli.

The sensitivity to feel depends on the person and the stimulus' location on the body, but as a general finding in sensing contact (pressure), the applied force has to be greater than 0.06 to 0.2 N / cm to be surely noticed. In practice the most pressure sensitive area is reported to be on a face and the least sensitive on a big toe. [Hale and Stanney, 2004] In most cases of contact the skin is more sensitive to a stimulus of a small surface than to a large one [Kortum, 2008].

However, when considering haptic sensations as an information channel, the sensitivity for pressure alone does not define the optimal skin location for perceiving information through touch. The best sensing location depends on the type of stimulus and what the sensation mediates: a gentle breeze of wind cannot be felt with a tip of a thumb nor can a texture of an orange be felt with the skin on the back. The right sensing area has to be chosen for each stimulus according to the receptor types in and their density in a particular part of skin.

The most haptically dexterous and, therefore, the most typically utilized part of the body for intentional haptic interaction is the hand with its fingers. As, out of the entire body, fingertips have the largest density of pacinian corpuscles, mechanoreceptors sensing rapid vibrations and adapting fast, it is not a conscience that many of the existing haptic interaction methods are based on hand or finger contact. [Raisamo and Rantala, 2016]

In interacting with the environment and manipulating objects the tactile sense through hands and fingers gives valuable perceptions of mass, hardness, texture, volume, shape and temperature. The information is gained through a variety of procedures of *haptic exploration* (Figure 8) [Lederman and Klatzky, 2009].

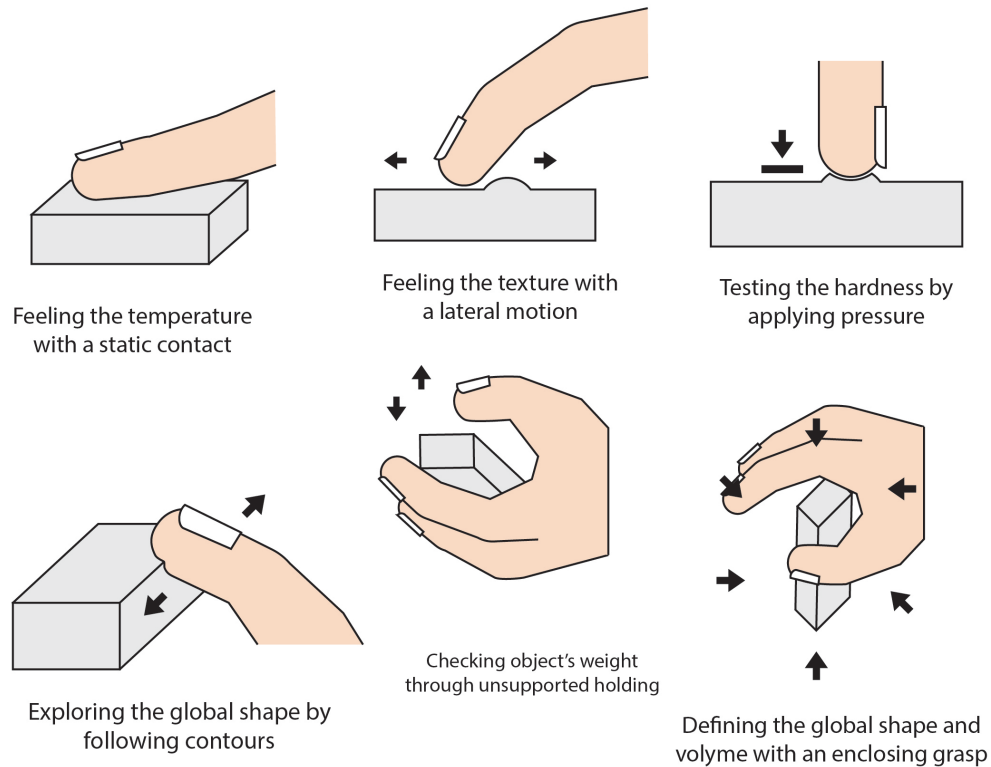


Figure 8. Explorative procedures. Visualization applied from Lederman and Klatzky [2009].

Whereas visual perception is usually the best suited to discrimination tasks relating to space, and auditory perception to settings in time, the somatosensory system perceives both spatial and temporal qualities. This is a great advantage in exploring and manipulating the environment especially when sight and hearing is defected [Pasquero, 2006]. However, there are limitations to what touch can “see”. Haptic perception is mostly proximal: the perceptual field is limited to the physical extent of touch contact. Sensations caused by radiation stimuli are the rare exceptions. The downside to the temporal properties of haptic perception is that the perceived information of an object depends on the duration and sequences of touch. Due to the sensory tendency to adapt to a haptic stimulus, the variation of parameters plays a major role in haptic perception [MacLean, 2008].

Though the haptic senses can be effective and efficient in communicating object qualities, spatial dimensions and physical affordances, touch can also easily be fooled or get discordant. There are several different factors that can have an effect on a person’s ability to identify a haptic stimulus. Stimulus location on the body, person’s age, gender, health, fatigue, state of mind, attention and practice are just some of the many

factors affecting the sensory capabilities. [Raisamo and Rantala, 2016] For example old age, tiredness, divided attention and lack of experience in distinguishing a certain touch sensation are common to decrease the ability to feel. Also a constant and monotonous stimulus is eventually disregarded due to the adaptation (numbing) of receptors [Hatwell et al. 2003]. Mostly due to these tendencies for the skin to react to the varying internal and external conditions, it is difficult to accurately capture and repeat a touch sensation [MacLean, 2008].

Pleasant – and unpleasant – touch sensations can behold much more to them than the receptor activity they trigger: feeling a hug from a mother or a lick from a friendly dog communicate messages in the most intuitive form. As an information channel, haptic sensations are intuitive in mediating pleasure and emotions. These sensations can arise either from the pleasantness of an object or the so-called interpersonal touch. MacLean [2008] speculates about the possibilities of utilizing touch’s emotional aspects in technology: “Affective haptic design can take us in one of two primary directions: toward a focus on what feels good in touched interfaces—for example, either active or passive manual controls—or toward computer-mediated interpersonal touch” [MacLean 2008, p.161]. This thought offers an interesting perspective to touch as a possible information channel in technology.

When designing and evaluating haptic sensations in terms of information communication, one more note is made in many contexts: “Haptic design is nearly always multimodal design” [MacLean 2008, p.157]. It seldom communicates alone; it is often used to reinforce other modalities or to enrich the interaction. Even when it is the primary modality, it is common to accompany it with either parallel or sequentially presented clues for eyesight or hearing.

Haptic messages can be anything from a knock on a shoulder to interpreting words by feeling movements on a speaker’s face. From alarming to guiding and on to communicating status information and encoded messages, it is possible to tailor meaningful touch sensations through careful design.

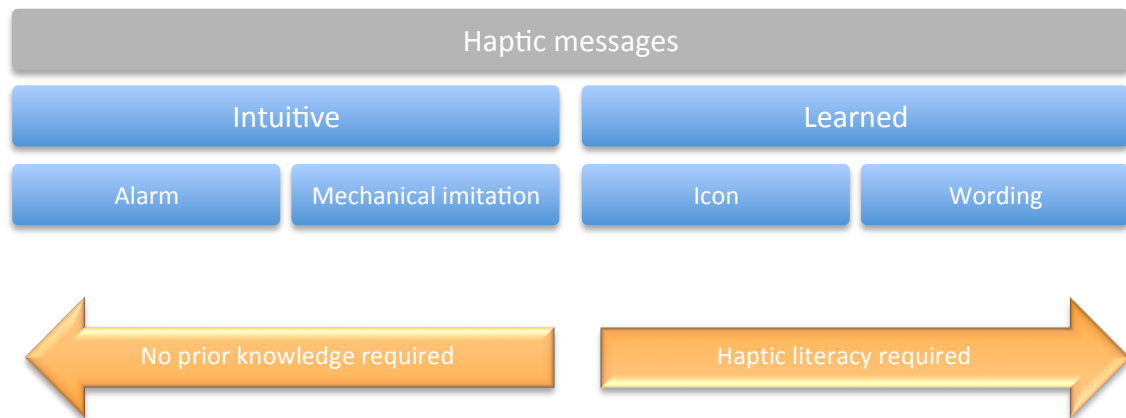


Figure 9. Types of haptic messages. Haptic messages can be divided into two categories according to how they interact with the user. The challenge in learning the meaning of the feature increase as the message becomes more complex.

In human–technology interaction haptic messages can be divided in two main categories: those that communicate intuitively and those that require learning (Figure 9). The intuitive ones consist of haptic effects that communicate simple messages such as an attention requiring alarm or a sensation imitating mechanical feedback such as pushing on a button. Receiving and understanding an intuitive haptic message does not necessarily require careful interpretation or any prior knowledge of the system, because many of the used sensations are similar to haptic interaction in the real world and indicate on/off -type of simple information.

As said, there are also haptic messages that require learning. These systems have the capacity to communicate detailed meanings to those who know how to “read” them. A complex haptic message can use different variables (described in the Chapter 6) to articulate information through a system of meanings, such as numbers, alphabets or ideograms. Out of these kinds of messaging systems the most common ones are tadoma (Figure 10) and braille (Figure 11).



Figure 10. On the left: Tadoma: communicating through facial movements [<https://www.flickr.com/photos/perkinsarchive/5977984907/>];



Figure 11. On the right: reading through relief-like dot writing (braille) [<http://1.bp.blogspot.com/-lWQZyU3COeM/TeJvREPy8I/AAAAAAAAAAMS/nYQIbVavQ5Y/s1600/Braile+00013545.jpg>].

The separation of haptic messages according to intuitiveness and the need for learning is not absolute, and in many commercial products haptic features are a bit of both. For example, on a mobile phone, vibration works well as a general haptic alarm feature that intuitively informs about on-going activities. However, similarly to choosing a particular ringtone for a particular contact, it is also possible to customize vibration with a specific pattern. The vibration pattern adds to the information content of the haptic message and if memorized, effectively communicates about the details of the incoming call.

Haptic messages may be felt passively or explored actively [MacLean and Enriquez, 2003]. Therefore, in designing haptic features, it is essential to know whether the interaction is about to happen through active or passive touch. The activity and

participation of the touching hand or a finger define what is required to create the sensation.

If a haptic message is communicated mainly through passive touch Brewster and Brown recommend the parameters to be: frequency, amplitude, waveform, duration, rhythm, body location and spatiotemporal patterns [Brewster and Brown, 2004]. In their work, Brewster and Brown apply these parameters to a vibrotactile pad, but the types of stimuli could be applicable also to pressure etc.

When a haptic message is read through active touch meaning that the hand or finger is free to explore the object, possible haptic variables are those that also play a role in the properties of physical buttons. According to Hoggan et al. [2008] these properties consist of: “Size, Shape, Color, Texture, Weight, Snap Ratio, Height, Travel Friction and Surround” [Hoggan et al. 2008].

3.3 Summary of haptic perception

Haptic (touch-related) senses are considered a very intuitive channel for perceiving and mediating information. The senses are a collection of individual feelings such as pressure, temperature, body posture and balance. Essentially the purpose of haptic senses is to communicate the body’s presence and state in its environment. Within this process haptic senses enable dexterous environment / object exploration and manipulation.

Striving from the receptor distribution throughout the entire body, haptic senses are largely considered as general senses. Unlike seeing, hearing or tasting the processes of haptic sensing are more independent from cognition and much quicker to develop. The spatial and temporal qualities of touch make it agile in object exploration and manipulation, though the proximal nature of it mostly demands a physical contact with the object. Haptic sensations depend on the duration and sequence of touch contact. Because of the body’s tendency to react to its internal and external conditions, it can be difficult to design and communicate accurate haptic sensations.

The receptor activity causing a haptic sensation can be categorised according to its location in the body (exteroception in skin, interoception in organs, proprioception in muscles and joints) and according to the type of receptor it stimulates. Each receptor type reacts only to a certain stimulus: mechanoreceptors to touch, pressure, skin stretch and vibration; nociceptors to pain, chemoreceptors to chemical changes; and thermoreceptors to temperature changes. While trying to utilise haptic sensations as an

information channel, it is essential to know which haptic qualities best match each body location and stimulus type.

Kinaesthetic (proprioceptive) and tactile (extroceptive) senses are mainly responsible for the physical perceptions of the world. Feeling the difference between walking on grass and pavement even with shoes on or changing the gear with a shifter while looking at the road are both example tasks in which kinaesthetic sensations matter. Similarly, recognizing a sharp knife from a dull one or knowing when a hot plate is too hot to touch is a matter of tactile sensations. Both of these haptic senses are relatively easy to activate, though to function well as an interaction channel, the sensations have to be clearly distinguishable. The greatest challenges for both of them are about perceptual accuracy and mediating meaningful messages and affordances, while the receiving people are not likely to feel the sensations in the exact same way.

Haptic perception is particularly useful for actively exploring object properties such as mass, hardness, texture, volume, shape and temperature. Most of the sensations from haptic exploration concern tactile stimuli, but the greater the dimensions are in space the more the kinaesthetic sensations participate in the exploration.

Another possibility for receiving haptic sensations is through passive sensing, commonly occurring through skin contact. In such a setting, sensations are communicated through an object that applies forces onto the contact surface. The forces can communicate a message by using for example varying frequencies, rhythms or spatiotemporal patterns. With passively mediated messages the encodings of the parameters are a significant challenge if the intention is to communicate complex messages.

When looking at haptic sensations as a communication channel, there are two ways to interpret a message: by intuition or by learning. The separation between the two is not always absolute. For example, in the case of a haptic notification: the suddenness is an intuitive indication of demanded attention, but the type of sensation can tell more about the noted context. This is a typical case scenario for example in the haptic user interface of a mobile phone.

Considering the extent to which haptic sensations can communicate about the environment and offer clues about on-going actions, it is unfortunate not to have utilized haptic sensations better in the recent designs of interactive touchscreen kiosks. The biggest loser in the current situation is undoubtedly the visually impaired to whom the graphical user interfaces are inaccessible. The situation is likely to change soon, as the awareness and demands for accessible interactive kiosk solutions is growing. The

major design challenges for such systems lie in developing the right haptic design approach and a capable execution for it.

In the context of user interfaces haptic feedback is an intentionally or unintentionally occurring touch sensation. Whether it occurs through physical or computed reactions it is beneficial in demonstrating affordances. Therefore, haptic characteristics are commonly used to highlight the meaning of physical elements such as a button to push or a handle to grab.

4 HAPTIC INTERFACES

Haptic interfaces have been studied for decades, though their presence in human–technology interaction has not been very noticeable in the everyday consumer environments. Beyond the vibration alerts of mobile devices and experience enhancing effects of gaming controllers there is a surprising variety of techniques for producing haptic sensations, and purposes to which haptic features are suitable for. This chapter presents the basics of haptic interfaces and shows interesting viewpoints to applying the touch sense into the touchscreen environments.

4.1 Basics of haptic interfaces

In the greater sense of interaction, haptic feedback often occurs unintentionally (from pushing down a button, driving a car over a bump or feeling the radiating heat from a powered hot plate), but touch sensations can be and are also used intentionally in communicating beyond the causalities of the physical world. By either imitating “real-world” touch sensations or mediating encoded clues, haptic interfaces enable touch-stimulating interaction with technology. In human–technology interaction, these systems are called haptic interfaces.

Until recently, industrial design has been indirectly and directly responsible for most of haptic interface qualities. In the process of product design, it has typically seen haptic qualities as designable but unavoidable interface features that are tied to the physical being of the product. In industrial design, some of the key design variants of these passive haptic devices have been three dimensional shapes, material choices and mechanics (for example in buttons).

Haptic interfaces have evolved into a more independent field of design within human–technology interaction. Distinct to haptic interfaces in HTI, touch sensations are created through computed processes with an intention to interact. Haptic interfaces can be divided into two main categories: active and passive haptic interfaces. In contrast to passive haptic devices, which are touch-communicative because of their natural physical form, the active haptic devices are designed to “exchange power (e.g., forces, vibrations, heat)” in order to simulate touch sensations [MacLean, 2008. p. 150]. The interest in these active haptic interfaces is growing now as an increasing number of interfaces are operated through touchscreens and the touch-stimulating design features that used to mark functions disappear.

Haptic interfaces come in many different forms. There are devices that are felt through contact with a finger or a hand, items that you wear, or items that are held in a hand like tools. Some of the applications of haptic interfaces are more expressive than others, but all of them interact through the same forces that are responsible for haptic sensations in the real world. The computer-generated touch effects create illusions of sensations, such as hardness, surface texture, force, strength and motion, such as vibration.

In haptic user interfaces, it is possible to use passive or active touch. If passive touch is chosen, touch stimulation will occur through a stationary hand or a finger, which means that the normal input of touching different screen areas cannot be applied. Though it is possible to provide a separate haptic messaging device (alongside the touchscreen) that could be used for example with the other hand; or to develop a different touchscreen interface layout for the stationary hand on the screen, the use of passive touch would disable the normal agility of touchscreen interaction. For this reason, it would be more natural to allow touch exploration on the screen and to support it with haptic clues.

Most typically interfaces with haptic stimulation are divided into two categories according to the used type of haptic hardware. There are *tactile displays* designed to create a sensation locally by *stimulating skin* (or other parts of body surface), and *force feedback devices* that model contact forces by *stimulating proprioception* (a.k.a. joint and other inner-body receptors). [MacLean, 2008]

Out of haptic hardware, skin-stimulating *tactile displays* can produce a wide range of haptic sensations. Due to the many types of receptors and the density of them in skin, it is possible to enhance not only sensations of pressure, but also stretch, vibration, temperature and even pain. Well-designed use of these sensations can effectively draw attention and enhance interaction in a user interface. Other benefits of tactile displays are their efficiency, compact size and low power consumption, which make them relatively easy to fit in with other hardware components [MacLean 2008, p.161]. Currently tactile displays are most commonly utilized in hand-held mobile devices with a vibration feature.

Force feedback devices are typically hand-held or hand-grasped objects that imitate the interaction of forces between the object and its virtual environment. While the human user is moving the device / control object (in the given degrees of freedom), the device produces counterforces according to the modelled force potentials. In consumer devices, force feedback is the most common in gaming devices such as joysticks and racing wheels. In non-consumer devices force feedback has proven useful in tasks, in which human dexterity and perceptual capacity for feeling is required, but the human subject cannot access the object in person due to environmental limitations.

Though haptic sensing is at its best when both external (skin) and internal (muscle and joint) sensations are included, unfortunately the two types of haptic hardware have not been so easy to combine. According to MacLean: “Haptic interfaces are generally directed at either the tactile or the proprioceptive systems because of configuration constraints” [MacLean 2008, p.153]. The problem with the hardware arises from the complexity of the natural exploratory procedures. In order to work together, the combining hardware should imitate both cutaneous and proprioceptive sensations by supporting both fine and large three-dimensional movements of active body parts.

Regardless of the restrictions in combining sensations, haptic technologies have successfully been able to address specific touch sensations. There are numerous ways to imitate the sensations related to exploratory procedures such as feeling for mass, hardness, texture, volume, shape and temperature. In addition, other perceptions, such as that of location, motion and rhythm/pulse, have been explored as an output.

In physical interaction with an object, touch sensing is activated in contact detection. Contact with an object is primarily mediated through the sense of pressure. If no changes happen in the initial pressure (that is applied to the skin through the contacting object), the sensation is likely to fade as receptors adapt to the pressure stimulus. If changes do occur, the perception can become more complex. The majority of information is perceived through the sensations following the initial contact detection, when for example a finger moves on a textured surface [Lederman and Klatzky, 2009].

As the sense of pressure is a natural outcome from a contact between the perceiving bodypart and an object, it is the first sensation to detect touch interaction. It can be either the perceiver or the contacting object that initiates changes to the intensity of pressure. Therefore, also in haptic interaction pressure can be used as both input and output. Force feedback is one of the types of systems actively utilizing pressure in both input and output channels. With force feedback devices a significant part of the perception comes from the motion-activated receptors in joints and muscles. However, sensations of pressure are a major source of information also as skin stimuli. As an output, applying pressure on skin surface has been used for example in wearable devices with pneumatic pressure and shape-memory alloy systems, and in imitating different types of clicking sensations with solenoid actuators.

Though haptic sensations are typically mediated through physical contact with solid objects, also other means of haptic stimulation can and do occur. These insubstantial stimuli are for example airflow, heat, gravitation, infrasonic tones and chemicals. It is worthwhile to keep in mind that interaction modes such as pressure, vibration and movement can be created with these means as well as with physical contact. However,

for sensations requiring precision, interaction through indirect contact might not be the best option, since the larger the area of exposure to stimuli is, the less precise the sensation is.

4.2 Role of haptic sensations in user interfaces

Touch is one of the less utilized senses in human-technology interaction. Though passive haptic features have been considered in physical control design for decades, haptic sensations are not yet automatically considered as an active part of the user interface.

There are three main reasons for why haptic sensations are currently not utilized to their full potential in UI devices. Firstly, in contemporary user interfaces relying on desktop-based systems, haptic qualities easily seem irrelevant in comparison to the visual design aspects [MacLean, 2008]. The majority of users rely on their vision and hearing rather than haptic clues. Therefore, in most of the current UI cases graphical design is considered the imperative output and audio the primary assisting modality touch feedback is typically treated as an optional bonus modality.

Secondly the users' touch-perceptual capacities and abilities present a problem for haptic interaction. (The greatest challenge in designing multimodal systems is keeping in mind the human perceptual capabilities. [Chang and Nesbitt, 2006]) "To our knowledge, most of the distributed tactile displays built to this day fail to convey meaningful tactile information and to be practical at the same time. The devices are too bulky or do not provide enough force to deform the skin." [Pasquero, 2006] The resolution of perceived touch sensation depends on a wide range of uncontrollable variation within and around the perceiver. From the design perspective, this is as difficult as defining screen brightness without knowing the user nor the surrounding light environment. Depending on personal factors a touch stimulus can be unpleasant for one while being unnoticeable to another user.

The third reason for why touch sense is still relatively rare in user interfaces is in the limitations of the touch sensation-enabling technology. Though new and interesting hardware solutions are constantly being developed, they are not always financially profitable to utilize and vice versa: the hardware that is easy and affordable to use cannot always produce a meaningful sensation for the user. "Lastly, they require constant maintenance or are too complex to operate most of the time." [Pasquero, 2006]

The most important reason for why haptic feedback has not been so successful is the combination of all three mentioned above. As a result the haptic system can easily end up feeling detached from the other interaction modalities, give an insufficient and unexpected stimulus and seem to support no intuitive logic.

Though the role of haptic sensations does not sound ground braking when looking at the use of it in currently common consumer devices, there is also evidence for a potential in improving usability and user experiences. In HTI research, the use of haptic sensations in user interface has been explored for decades with promising results. The use of touch sensations in HTI have been studied and acknowledged to have benefits for usability and positive effects on user experiences [Kortum, 2008; Hale and Stanney, 2004]. In detail, haptic feedback has been praised for its potential in “skilled performance tasks” and “virtual training” [Kortum, 2008. p.51], effectiveness in alerts, support for hand-eye coordination and meaningful clues [Hale and Stanney, 2004]. Currently haptic sensations are commonly utilized in notification modalities [Warnock et al. 2013, Warnock et al. 2011] modalities for mobile devices [Hoggan et al. 2009]. Adding haptic modalities is known to strengthen the interaction with touch screen devices [Hoggan et al. 2008], improve the usability of a self-service device through adaptive use of modalities [Hagen & Sandens 2010], and error reduction [Kortum 2008].

Many technologically generated haptic features have been designed to compensate the lack of real-world-like touch sensations. This is common especially with touchscreen interfaces. However, it has also been stated that it is not enough to merely “replace the feel of mechanical buttons” [Banter, 2010]. Instead, haptic feature could be used to create holistic entities to design more engaging user interfaces: “Developers will be able to move in creative directions that are not possible with touch screens alone or mechanical buttons.” [Banter, 2010].

Though bold new approaches might be welcomed within the professional field, research with users suggests that conventions should not be overlooked. McGookin et al. [2008] report in their paper that “in spite of their [the user’s] awareness of using a touchscreen overlay on the device“ some of them might “have expected the controls to operate as ‘real world’ buttons” [McGookin et al. 2008, p. 304]. Though the research in question did not report significant problems with the mismatch of the user’s mental model and the device’s haptic behaviour, it is an example of how strong perceptual expectations can be. Also Kortum [2008] mentions ensuring “Realistic Display of Environments with Tactile Devices” as one of the points in his design guidelines. To conclude: it can be considered a solid starting point to start design of haptic allegories (what sensations mean as a general concept) from touchable environments that are familiar to most users.

4.3 Touch stimulation in touchscreen user interfaces

So far touchscreen interfaces have – for a good reason – had very little to do with the haptic sense. As listed previously in the advances and experiments in the field of haptic technology, current consumer touchscreen devices have been able to utilize tactile feedback mainly just through vibration.

In contrast to button UIs, in touch screen UI's the position of buttons and controls is dynamic and often very difficult or impossible to anticipate. It would be possible to try solving the placement issues with a strict alignment to a grid like structure, but even still, changing screen views and their functions could not always be presented alike. Also, a static layout of the controls on a touch screen would hinder the flexible presentation of information (which should be optimized to the situation and user's particular needs).

Each physical touchscreen device has its own certain haptic properties in terms of mass, hardness, texture, volume, shape and temperature. In addition to these natural qualities of the device, it is possible to alter some of the properties with a haptic interface.

4.3.1 Sensations from direct touch contact

Out of the haptic properties of a touchscreen surface shape and texture can be made to change with haptic technologies that involve direct touch contact. There are tactile actuators such as vibrating motors, solenoids, piezoelectric actuators and electrode sheets that can be used to alter the real-world sensation from touching a touchscreen.

In interactive kiosks perhaps the most dramatic change in replacing physical buttons with touchscreen interfaces has been about the changed properties of the surface shapes from 3-dimensional to 2-dimensional elements. There are simple solutions for bringing some elevation to the otherwise flat surface with a physical overlay, such as an assistive grid on a film to the visually impaired, but the problem with them is that they cannot adapt to the graphically changing content in different stages of the navigation. To match the versatility of the graphical user interface, it would be ideal to bring a third haptic dimension to the perceptive space. There are some existing techniques for creating shape with a graphical screen, but the capacity of those applications is limited to bending the entire screen in our out [Laitinen and Mäenpää, 2006]. More elaborate

techniques for creating three-dimensional shapes onto a flat level exist, but currently they are still difficult to use in combination with the graphical touchscreen.

The most common way to affect the touch perception in a direct contact with a touchscreen device is the use of vibration. Vibration is one of the most common forms of haptic stimulation, because it is somewhat easy to produce. It is typically produced with eccentric rotating mass motors, voice coil motors or ultrasonic transducers; which mediate fast movements that are perceived as vibration. It is also possible to produce electrostatic vibration, which does not create physical movement, but changes the friction between the surface and the perceiver's finger. Vibration, electrostatic forces and ultrasonic vibrations are some of the technologies behind the recent explorations with texture imitations on touchscreen surfaces.

Vibration can be used both as an on-going feedback, while the user is interacting with the system, or as a post-action feedback, launched as a reaction to the user's action. In devices such as the mobile phone it is often a form of post-action feedback, while in gaming devices it is used to enhance the experience and to bring a physical aspect to the interaction. If used to create an illusion of texture vibration is given along with the touch contact.

Though the illusion of texture is a fascinating a potentially versatile haptic feature, in graphical user interfaces, vibration is mostly used for giving feedback and alerts (in addition to visual changes and notifications). Vibrotactile stimulation is made popular by its availability, inexpensiveness and the relatively good adaptability in hardware. If adjusted correctly it produces an effective and pleasant sensation without overriding other output modalities.

The downside to vibration as a haptic expression is that the vibrotactile qualities in user interfaces are not always successful. Due to the challenges of controlling the vibrating mass accurately, vibration tends to have a low temporal resolution; the beginning and ending of the sensation are hard to define. Another challenge concerns the recognisability of the sensation as a message. Beyond the expressions for an alarm or a special notification, understanding vibrotactile feedback depends much on learned codes. The last but not least of the major issues is the intensity of the vibration in its context of use. The caused effect does not only depend on the settings of the vibration motor, but also on the user's individual sensitivity, the sensitivity of the exposure area in the body, the mediating materials and constructions and the other possible haptic stimuli in the environment. If adjusted incorrectly the danger is that the vibration can be perceived either weak and unnoticeable or disturbingly strong and uncomfortable. To

avoid mistakes in designing vibration feedback, the feature should always be tested in its intended environment and with a variety of users.

As mentioned before, vibration can also be made to create an illusion of friction as if an expression of surface texture. Electrostatic forces [Bau et al. 2010] and ultrasonic vibrations [Fujitsu, 2014] have been researched for several decades in efforts of creating the feeling of friction. Electrostatic vibration happens by conducting a low voltage onto a thinly insulated surface a finger can feel a slight vibration as if the surface's texture is rough or rubbery. Like so many others, this technique of enhancing haptic sensations is not common out in the market in consumer products, but trademarks such as Electrostatic Vibration (formerly known as TeslaTouch) (Figure 12) [Xu et al. 2011] and Senseg FeelScreen (Figure 13) [Senseg, 2015] have given visions for the future of electrovibration. Ultrasonic vibrations by Fujitsu (Figure 14 and Figure 15) advertise themselves similarly: “a technology that creates a sensory illusion of bumpiness and roughness”. Their technology is based on ultrasonic vibrations: “display creates a high-pressure layer of air between the screen's surface and one's fingertip, which has the effect of reducing friction, creating a floating effect“ [Fujitsu, 2014].

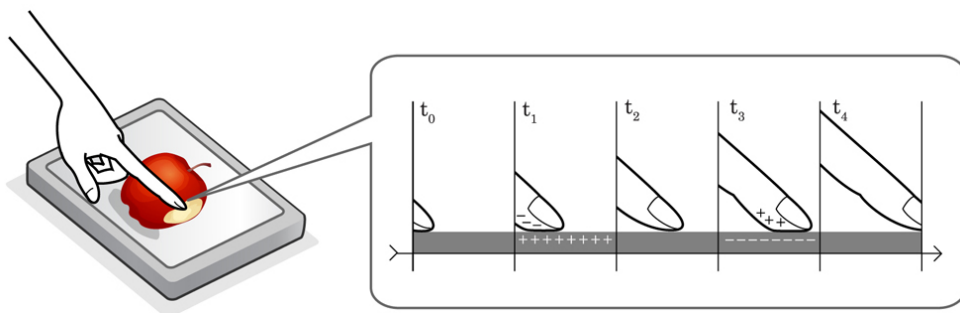


Figure 12. Illustration of Electrostatic Vibration in TeslaTouch.
(<https://www.disneyresearch.com/project/teslatouch/>)



Figure 13. Senseg (http://androidspin.com/wp-content/uploads/2012/01/IMG_20120111_124447.jpg)

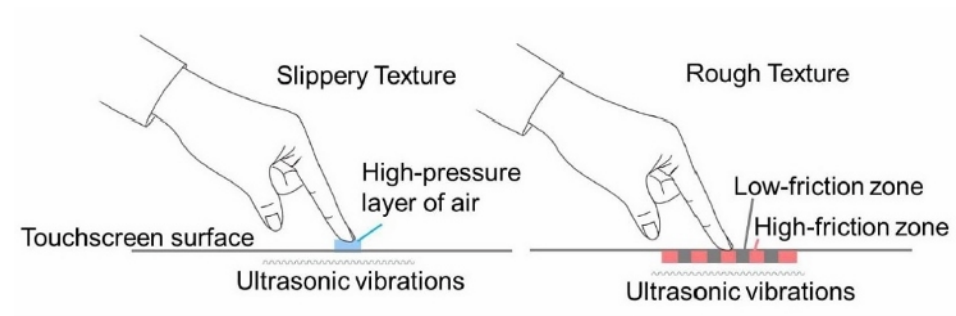


Figure 14. Illustration of the Fujitsu prototype. (<http://www.pcmag.com/article2/0,2817,2454004,00.asp>)



The prototype tablet with haptic sensory technology

Figure 15. Fujitsu's tactile touch screen. (<http://www.pcmag.com/article2/0,2817,2454004,00.asp>)

4.3.2 Indirect touch contact

In theory, not all interaction with touchscreen devices would have to happen through direct touch contact. There are forces that could enable haptic feelings even when there is no immediate contact with the touchscreen. Even now some users might choose to use their personal tools such as a touchscreen pen or a glove, to dial through the interface flow without forming a direct skin–screen contact. When considering the use of assistive tools as a main method of touch interaction, a different variety of touch sensations opens up for haptic design.

In the effort of adding haptic feedback to touchscreen interfaces there are some options beyond the contact with the screen itself that could enrich the touch experiences while interacting with the screen. If the haptic feedback-enabling technology does not have to be merged as an additional physical layer along the touchscreen, there are other interesting options for creating haptic virtual reality above the screen surface. In those cases sensations can be imitated and faked with forces such as air or magnetism that create a third dimension onto the interaction surface.

Recently several concepts (Ultrahaptics, Haptimime, Haptoclone, Mistable) have been demonstrating the use of ultrasonic mid-air haptic feedback. The mid-air haptic sensations are often enabled by ultrasound or vortex rings creating local changes in air pressure that are perceivable by touch. As with many other touch sensations, the accuracy of the perception might not be very high, but even with the vaguest touch feedback the ultrasonic mid-air haptic sensations could potentially establish a distinct sense of connection between the device and the user. Another significant benefit to this type of contactless touch sensation would be the improved hygiene, when skin contact on surface would be minimized. This is an important factor especially in public devices. [Subramanian et al. 2016]

Some prototypes have proven that a haptic interface can use magnetic force fields sensed with a responding pen or a wearable device. The force fields can simulate for example where the interactive elements are and give clues about the button's activity by giving it more or less magnetic resistance. As said, in order to feel the magnetic forces there would have to be a touching tool, such as a pen or a wearable item, through which the force could be received.

With FingerFlux (Figure 16), a prototype developed and studied by Malte et al. [2011], near-surface haptic feedback could produce sensations of pulling and pushing and illustrate the haptic space for example by enabling a “snap to grid” –property [Malte et al. 2011]. Malte et al. also propose that the use of a variety of tools, such as a finger

ring, stylus or a glove, would be possible. The DoCoMo Touchable 3D (Figure 17), is a similar concept allowing a stylus holder to feel the onscreen actions in mid-air [Miles, 2011].

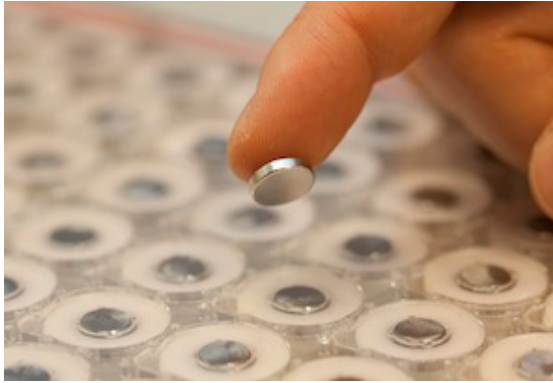


Figure 16. FingerFlux: Near-surface Haptic Feedback on Tabletops – Magnetic guiding for touch (<https://www.youtube.com/watch?v=trM7mXOjNFY>)



Figure 17. DoCoMo Touchable 3D (<http://www.pocket-lint.com/news/108696-docomo-touchable-3d-concept-screen>)

Other additional haptic technologies to use along graphical interfaces through separate hand-held tools could be electrorheological fluids and shape-memory alloys and thermal actuators mounted onto a hand-held or a wearable device. Studies have shown that even when the haptic sensation does not come directly from the same source as the visual clue, the overall perception can be enriched by other simultaneous haptic feedback. As an example, Richter et al. [2012] demonstrated that thermal clues are effective even when used as a separate output from simultaneous touchscreen touch interaction [Richter et al. 2012].

However, there are two major challenges with the thought of utilizing a separate haptic tool. First of all, the more complex the actuators are the more expensive the touch tool is likely to be. Therefore, in terms of cost-efficiency it would be difficult to include the

haptic device into the kiosk/vending machine. The other option would be to obligate visually impaired users to possess a personal haptic tool for interpreting the haptic interfaces. The same problem related to costs would be likely to emerge, unless the user's counterpart would be simple enough and serve a purpose in a wide range of touchscreen interfaces. Without standardized commonly utilized solutions, indirect touch contact is unlikely to become an easy solution for producing haptic sensations in a public touchscreen interface.

4.4 Summary of haptic interfaces

Though haptic interaction can be used to describe interacting with almost anything, in human–technology interaction it has become a term covering technologies that aim to provide stimuli for the sense of touch. For the past decade or so, haptic interfaces in consumer devices have been most common in gaming equipment and in mobile device. They have also been successfully utilized in robotics especially in assistive, medical, industrial and military environments.

As there is a large variety of haptic applications, there are also many methods of mediating haptic sensations. Depending on the intended functionality of the sensation, haptic interaction can be mediated through hand-held or wearable tools or by enabling any type of a contact between the force-sending device and the receiver's body. Some of the most typical hardware for touch stimulation is joysticks and DOF (multiple degree of freedom) styluses, exoskeleton devices, and mechanically or statically dynamic surfaces.

In terms of transmittance, haptic interfaces can be observed and analysed from three categorical perspectives: by the hardware type, the interactive qualities and the physicality of contact. Haptic interfaces can be divided into two main types based on the used hardware: tactile displays, which stimulate skin; and force feedback devices, that stimulate the body on the level of muscles and joints. Though the definitions are not absolute, because an application can utilize both stimulation types at the same time, it is helpful to use the terms to describe the general characteristic of the application.

Considering the participatory nature and the level of interactivity of the haptic interface the main variant is the physical activeness/passiveness of the participant's touch. From the point of view of perception, it makes a great difference whether the person uses his own moving abilities to explore by touch or if the perceiver is a passive observer of the

given stimuli. The transmitting applications characterized as passive haptic devices are mainly used for signalling feedback, whereas active haptic devices are giving as well as receiving touchable sensations. Active haptic devices have been shown to be more intuitive due to the interaction within the same modality (haptic output and haptic input), but passive haptic devices have so far been easier and more affordable to produce.

The physicality of the contact is one of the important criteria dividing haptic interface types. Most commonly both force feedback devices as well as tactile displays utilize physical contact with the perceiver to mediate touch sensations, but body stimulation without a direct contact is possible also for example through airflow and heat. While haptic perception is particularly skilled in exploring three-dimensional objects through direct skin contact, in terms of touch interaction in public interfaces, hygiene gives a strong justification for utilizing contactless stimuli.

When innovating haptic features that would function along touchscreen interfaces, some technical executions and interaction methods are more likely to work than others. Due to the dimensional limitations, a touchscreen with its flat surface cannot effectively produce large movements as a haptic feedback. Haptic characteristics such as friction, vibration and subtle shape (through memory alloys) can be integrated into the surface, but practice costs still hinder the development of such applications.

There is no reason why touchscreen kiosks could not utilize haptic sensations to better include visually impaired users. It is perfectly possible to add haptic characteristics such as expressions of texture or shape, motion or rhythm and to use them as symbols to add an additional information level. However, as touch perception is not like eyesight, it is advisable not to merely create a haptic overlay of all the graphical content on a touchscreen, but to choose carefully which interface features are worth haptic expressions. Thereafter the main difficulties lie in deciding on what the wanted effect is and how it would be made recognizable enough.

5 HAPTIC DESIGN – ENCODING CLUES

As explained in the previous chapters, haptic features can be transmitted and processed in many ways. To add to the complexity, there are also endless possibilities for the methods of encoding meanings through design. All this adds up to a complex bundle of haptic design choices that seem quite difficult to evaluate.

In this chapter I present a way to approach haptic design decisions in a systematic way and form clear ideas on how to design haptic features on a touchscreen. As the previous chapter concerning the framework of haptic design demonstrated, haptic design is largely case-specific. The user's perceptual capabilities vary due to physiological and mental changes as well as environmental factors, making it impossible to design a haptic experience that would be felt in the same way everywhere and for everyone. To tackle this challenge of going beyond generalities I have identified a single interface type to be used as an example.

The chosen interface content is often a part of a larger interface but in some cases also functions independently. Its content is essential in many interactions and therefore, its functionality is crucial. The chosen example user interface is a *numeric keypad*. The relative simplicity of the keypad's functional content allows the applied design approaches to be examined more independently from complex contextual factors.

In this chapter, I will first approach haptic design from the perspective of perceptive affects of multimodality. Having gone through some of the possibilities and dangers in combining modalities, I proceed to explain about Nesbitt's "Multisensory Taxonomy", and its perceptual units as a method of categorizing multimodal design space [Nesbitt, 2006].

The main body of this chapter consists of a closer look at touch-perceptual units and their metaphorical use as haptic design. I aim to take a critical approach to Nesbitt's theory as I apply its principles to my chosen example interface scenario.

5.1 The example UI: numeric keypad and its challenges

Numeric keypads present themselves usually in user interface situations when dialling a number to call to, an arithmetical operation, a code to enable access, naming a target marked with a number, or entering any kind of numeral data in one or more digits. A keypad is commonly presented with designated content to allow the entering of a number (0-9) or a number series. Depending on the use case, the layout and content can

vary, but the two most commonly used layout compositions are the telephone keypad and the numeric keypad in calculator contexts (Figure 18).

Num Lock	/	*	-
7	8	9	+
4	5	6	
1	2	3	Enter
0		Del	

1	2	3
4	5	6
7	8	9
*	0	#

Figure 18. The two most common numeric keypad layouts: a numeric (computer or calculator) keypad and a telephone keypad.

Although a number pad usually constitutes of the same elements, there are some different ways to construct its layout. In touchscreen interfaces a keypad layout is usually presented in a grid of 3 columns in 4 rows. Occasionally controls can be arranged in any context supportive way (Figure 19). Especially when other entry items such as alphabetical characters or action keys (“ok”, “cancel”) are presented along numerals, the content of the keypad might be arranged very differently from a 3x4 grid.

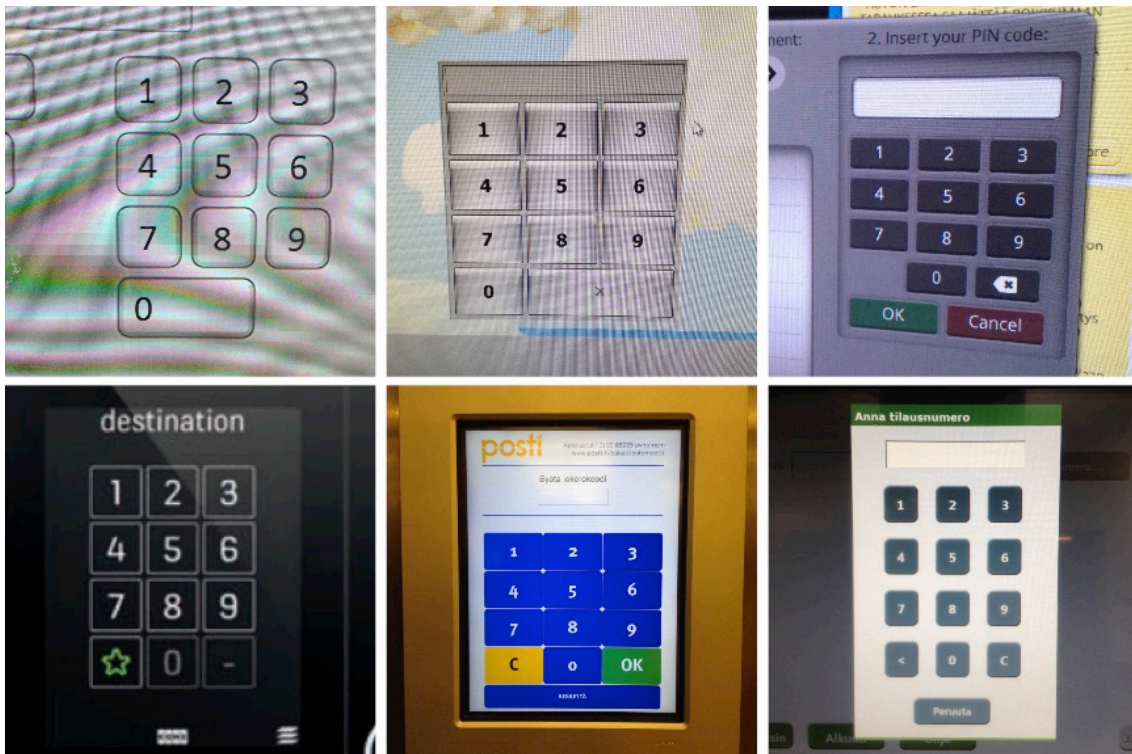



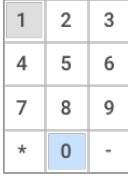

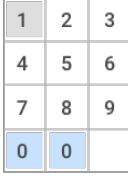



Figure 19. Some of the currently used keypads in touchscreen vending machines and information kiosks. From left top-corner to right bottom: shopping mall information kiosk, movie ticket vending machine, condominium information board, elevator call device, post locker interface, train ticket vending machine.

In order to validate a keypad layout that is commonly used in touchscreen contexts in public, I observed and documented (Table 1) number layouts in vending machines in action. I browsed the content of 13 touchscreen self-service devices, out of which I found 7 to have numeric keypads. I was expecting the findings to verify one type of number layout as the most common one, but to my surprise, the observations showed a significant variation of keypad layout. Most differences were within the bottom row.

This unexpected variation clearly demonstrated that the contents of touchscreen interface keypads have significant differences. Furthermore, it verified the potential challenges of use for the visually impaired users: an assumption of what is on the touchscreen keypad is not sufficient while the key contents in public interfaces can be different.

Type of vending machine	Purpose	Numeric keypad	Keypad context
Train ticket	Buying and collecting tickets		Keypad presented as an independent number-only entry
Post package	Sending or collecting parcels		
Condominium info board	Managing bookings and messages		
Elevator call	Defining elevator journey's destination		
Movie ticket	Buying and collecting tickets		
Shopping mall information	Guidance and wayfinding		Keypad presented along a keyboard.
Office lobby	Announcing arrival to an appointment		
Coffee	Paying, choosing and making coffee		No keypad found.
Photo booth	Taking a self photo		

Slot machine	Gambling / gaming		
Library kiosk	Lending library material		Not collected.
Healthcare centre lobby	Announcing arrival to an appointment		
Photo printing	Creating prints from digital photos		

Table 1. Real world references. The most significant differences are within the contents of the bottom row of observed keypads. The number zero is most often placed in the centre; in two cases it was placed to the leftmost column. Other common contents relates to removing or cancelling the entry. These actions are placed variably onto the corners of the grid.

Due to my findings I decided to specify my example case and its design challenge in the following way:

The design task within this chapter is to suggest haptic clues for a 3x4-grid touchscreen keypad. The used example consists of 12 buttons: 10 numbers (0-9), an “OK” for confirmation and a “<”-sign for removing entries. Other functions are not included in the example keypad, but the use of them is briefly discussed in terms of creating haptic distinction between common and uncommon items (Figure 20). Though the spatial layout (location within the grid) is likely to offer the most significant clue for recognizing the items, the suggested haptic design should ensure the identification of individual items even if the arrangement does not follow the expected logic.

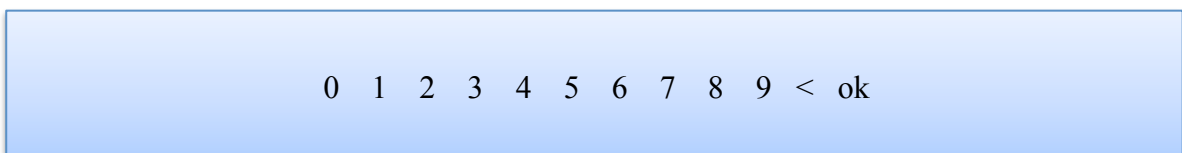


Figure 20. The example keypad consists of 12 buttons. This content will be used to formulate ideas on how haptic design could be applied to construct distinction and meanings.

Further on when I make my recommendations based on my chosen design approach, I focus on the design variables rather on the technical execution. I feel that the technological solutions can be somewhat adoptable whereas the underlying design principles ought to follow certain structure for the sake of multimodal consistency.

5.2 Haptic design and multimodality

When designing for users with impairments, the possibilities of utilizing more than one active sense in interaction should never be overlooked. As the brief introduction to visual impairments in Section 2.2 demonstrated, the majority of the impaired can see to some extent. This presents a challenge: even though the visual perception might not be perfect and clear, it can still affect the overall perception along other sensory impressions. Therefore, some words about the effects of combined modalities are in place.

Multimodality, which refers to the designed use of more than one sense, has been generally acknowledged to be beneficial in interaction. Depending on the chosen approach the achieved benefits can be slightly different, but in general, thoughtful combination of modalities can increase the accuracy, efficiency, naturalness and perceptibility of interaction [Maybury and Wahlster,1998].

Combining modalities can alter the perception of even the most well designed haptic feature. Just as great advances can be made when modalities are designed in tune with one-another, also careless combinations can send conflicting messages and spoil the clarity of the interaction. Therefore, it is important to be aware of the possible effects and consider the method of multimodal fusion carefully from the beginning of the design process.

Nigay and Courtaz [1993] presented a division of “multi-feature system design space” in which combinations of modality are categorized according to the use of multimodalities and the method of their fusion. In the model the criteria for analysis is A) the sequential or parallel use of modality; and B) the independent or combining nature of the fused modalities. This division provides four categories describing the nature of the multimodal interaction: the synergistic, concurrent, exclusive and alternate forms of multimodality. From each of the four sections of design space it is possible to identify two levels of abstraction: those with meaning and those with no meaning. [Nigay and Coutaz, 1993]

		Examples of use in practise		
		Modality 1 (f.ex. visual)	Modality 2 (f.ex. haptic)	Main benefit
Parallel use of modality	Synergistic: same information communicated redundantly	Main focus	Main focus	Redundancy
	Concurrent: special aspects of the information are highlighted with another modality	Main focus	Notification	Saliency
Sequential use of modality	Exclusive: same information is presented through optional channels	Mode option 1	Mode option 2	Adaptation (the best suited sense to each user preference)
	Alternate: each modality is used in separate tasks within the same system	Mode in task 1	Mode in task 2	Adaptation (the best suited sense to each task)

Table 2. Possibilities of combining multiple modalities. These multimodality types are based on a “multi-feature system design space” by Nigay and Coutaz [1993].

Whether the use of modality is parallel or sequential, there is a possibility that the first appearing or otherwise more dominant modality affects the interpretation of the other modality. This so-called congruence effect has been studied with different modality combinations, and in a paper by Martino and Marks [2000] the effect was validated also in a task combining visual and haptic features:

“...participants could not attend wholly to stimulation of one modality without intrusion from stimulation of another modality. Both when participants attended to touch and when they attended to vision, performance was affected by activity in the unattended channel.” [Martino and Marks, 2000]

Table 2 above demonstrates the categories of Nigay and Courtaz in and gives practical examples of what each definition means. In this context the categorization focuses on output rather than input, because I consider the haptic input method of the touchscreens

in question sufficiently usable. In comparison, the design space model of Nigay and Coutaz is more about the proactive functioning mechanisms whereas Nesbitt tries to approach the challenge of how the design of each modality should take one another into account. While Nesbitt aims at building thoughtful metaphors and Nigay and Coutaz a categorization of multimodal interactiveness, considering haptic design ideas from both of these perspectives is likely to give a good overview on how the designed elements function in the big picture. However, in the context of this work I chose to take an in-depth look into the Multi-sensory Taxonomy rather than division by Nigay and Coutaz, because the taxonomy gives a more practical view to the aspects of multimodal design.

5.2.1 Multimodality in the context of this work

Multimodality matters especially in situations in which one sense cannot offer the needed coverage for perceiving the entity. Noise, disturbance, the user's physical or cognitive impairment or strict concentration on a certain type of stimulus can easily block out features or events that should be noticed. In such situations, adding an assistive modality that reaches out from some other perceptual dimension can help to make important messages more noticeable and powerful. For this reason, interactive kiosks and vending machines have special demands for interaction capacity. Therefore, they are excellent targets for multimodal interaction design.

As clarified in the beginning of this thesis, the challenges caused by lack of vision can be decreased with additional auditory or haptic features. While the auditory modality can compromise the privacy of the interaction, haptic interaction by its nature offers a more private and subtle interaction channel. As haptic interaction also plays a role in interacting with physical user interfaces, its presence along the visual modality is well expected and intuitive, if consistently applied.

5.2.2 Multisensory nature of touch interaction

“Haptic design is nearly always multimodal design; the touch sense is generally used in conjunction with other sensory modalities, whether their roles are to reinforce the same task or to handle different tasks performed at the same time.”

[MacLean 2008, p.157]

Most tasks that benefit the most from haptic interaction occur while multitasking a.k.a. when cognition is loaded by more than one type of stimuli. “For example, in some circumstances, a controlled adaption in salience or detectability is desirable when workload increases; some important icons are still being noticed, but less critical ones “wash out” when more urgent tasks are in play” [Chan et al. 2008].

Multimodality can have a significant impact on the perception even if the modalities are not intended to influence one another. This is a crucial observation for the sake of haptic design since it almost always inevitably is multimodal design. This realization reinforces the conclusion that good haptic design cannot be defined with strict design guidelines, but design recommendations are greatly dependent on task type and environmental contexts [MacLean 2008; Tam et al. 2013; Nesbitt 2006]. While instant guidelines cannot be given, it is, however, worthwhile to approach the design space and metaphors with a strategy.

“Good designers must understand the range of possibilities and therefore one of first steps in formalising the design process is to categorise the design space.” [Nesbitt 2006]

Design of variables, also known as “perceptual units” are typically seen modality-related: information visualization maps data attributes to “units of visual perception”, while information sonification does the same with sound, and so on [Nesbitt, 2006]. However in multimodal interfaces such as a touchscreen device, which aim to utilize different senses as a combination, it is advised to consider the complementary properties of the modalities as an entity [Oviatt, 1999].

To better support the overall mappings between information and perceptual models, Nesbitt [2006] proposes a different approach to the division of design space. To support multi- and crossmodality his division (“Multi-sensory Taxonomy”) is based – not on the sensory domain (Figure 21) but – on the comprehensive underlying information metaphors of *space*, *time* and the sensory channel related *direct properties* (Figure 22). The benefits of this type of approach are that it “enables the reuse of concepts across different senses” [Nesbitt, 2006 p.4]; that the common framework eases the comparison between different modalities; and that redundancy in multimodal interaction strengthens the message for the perceiver [Maybury and Wahlster, 1998].

According to Nesbitt’s theory, spatial, temporal and direct metaphors form the most commonly applicable division for metaphors. Using them rather than the traditional division to modality, offers better support to multimodality.

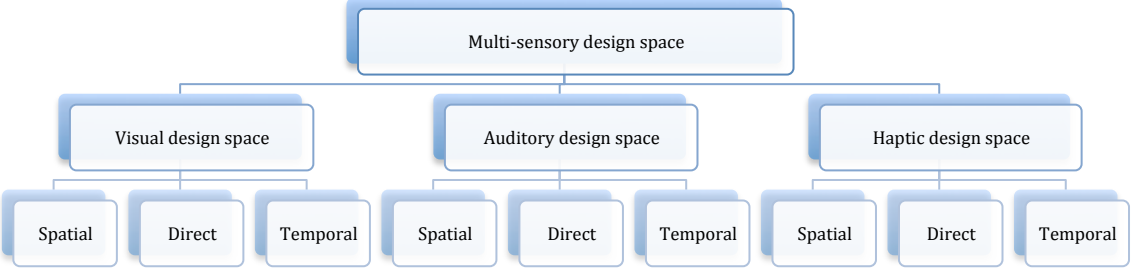


Figure 21. The typical division of design space focuses on a single modality, which then can be identified to have certain design properties. An illustration according to Nesbitt [2006].

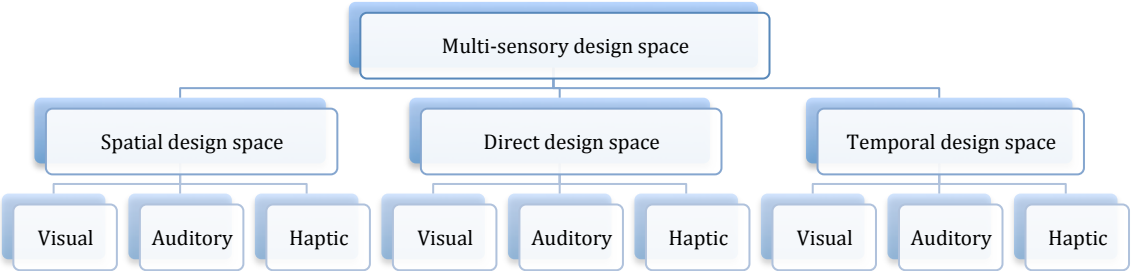


Figure 22. A high-level division of the design space by Nesbitt; An alternative model is independent from the sensory modalities and introduces a multimodal approach for designing with metaphors by Nesbitt [2006].

5.3 Haptic design space – theory and practice

The spatial, temporal and direct divisions of design spaces make it possible to identify similar features in different modalities. When these modalities are used together in one interface system, the touch points in which two or more modalities utilize the same design space can and should be used to build coherence. Coherence supports the system logics and the user’s intuition. Furthermore, by enhancing the concepts of design spaces, the features of different modalities can be built up to effectively communicate designated metaphors.

5.3.1 Spatial design space

As we know touch to be a spatially oriented sense, spatial design has a lot of expression power when it is well used in haptic design. Therefore, understanding the different aspects of spatiality in terms of design choices is crucial in producing intuitive haptic clues.

According to Nesbitt [2006] *scale*, *location* and *structure* are the three main building blocks for spatial metaphors. Though these concepts are the same with all modalities, depending on the perceiving sense their nuances can vary. The other major division Nesbitt makes, is about the general concepts of spatial metaphors. They are divided into three categories: the *display space*, the *spatial structure* and *spatial properties* (Figure 23). The display space defines the context, spatial structure sets the rules within it, and beneath the structure there are individual spatial properties that define the characteristics of individual elements. [Nesbitt, 2006]

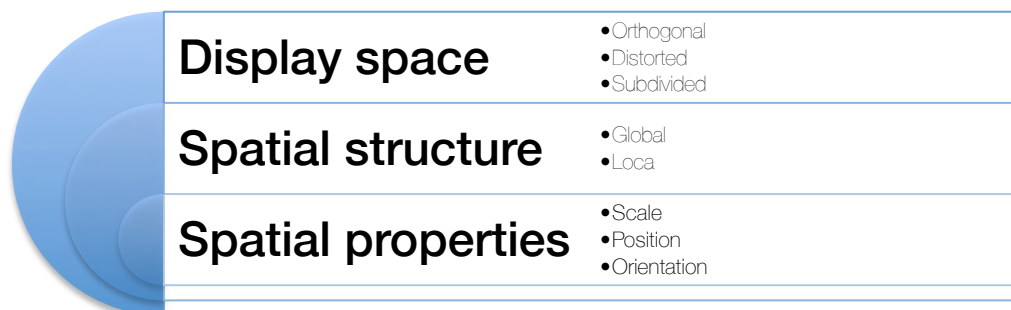


Figure 23. High-level components of spatial metaphors according to Nesbitt [2006]

All spatial metaphors depend on the nature of the *display space* to arrange the display elements. While the concept of display space is relatively constant and concrete in the real world, in HTI design of modalities display space can be a much more abstract concept [Nesbitt, 2006]. This is a factor that demands attention from the designer, because the display space can present itself in three different dimensions: orthogonal, distorted or subdivided. The division depends on the fragmentation and distribution of the haptic perceptual field(s) [Nesbitt, 2006].

In touchscreen environments such as electrostatic screen surfaces the display space's dimension would likely be orthogonal, as the haptic interaction is enabled in two dimensions along the screen. A cell phone's vibration in a user's hand could be seen likewise orthogonal, though the entire object with all of its three dimensions would be active. Force feedback systems such as 3-, 6- or 7-DOF (degrees of freedom) devices, can be seen as examples of distorted display spaces, due to the possibility of bypassing the constraints of physics. The so-called subdivided display spaces can be seen to emerge for example in cases in which haptic stimuli trigger different receptor types such as pressure (mechanoreceptors) and heat (thermoreceptors) at the same time.

In a situation of interaction, once the user has identified the overall interaction space, it is important to give an overview of the content a.k.a. the spatial structure. The more quickly patterns can be identified the more quickly the user can form an idea of the overall content. Once perceived, the concept of the spatial structure forms, modifies or corrects the user's mental model to a more accurate direction.

Nesbit's second spatial concept, the *spatial structure*, can be divided into two segments: a global and local spatial structure (Figure 24). Together these structures "occupy the display space" and define the reference points for spatial properties. Nesbitt's best explanation of global and local spatial structures is drawn into one of his charts (Figure 20). The chart points out global structural elements such as connection, grouping and containment; and local spatial structures such as area, line and shape. [Nesbitt, 2006]

Within a display space, elements can be seen to form structures for example in terms of their internal and external connections, grouping, similarity and exceptions (Figure 24). Though these relationships are often defined according to visual characteristics, the same types of features can be perceived through spatial touch perception. For example, while feeling keys on a keyboard, it is easy to understand that the alignment, grouping, shape and containment of keys on the interaction area are in fact markers of the global spatial structure of the interface. The structure is meaningful because it offers crucial reference points for identifying elements and interpreting affordances.

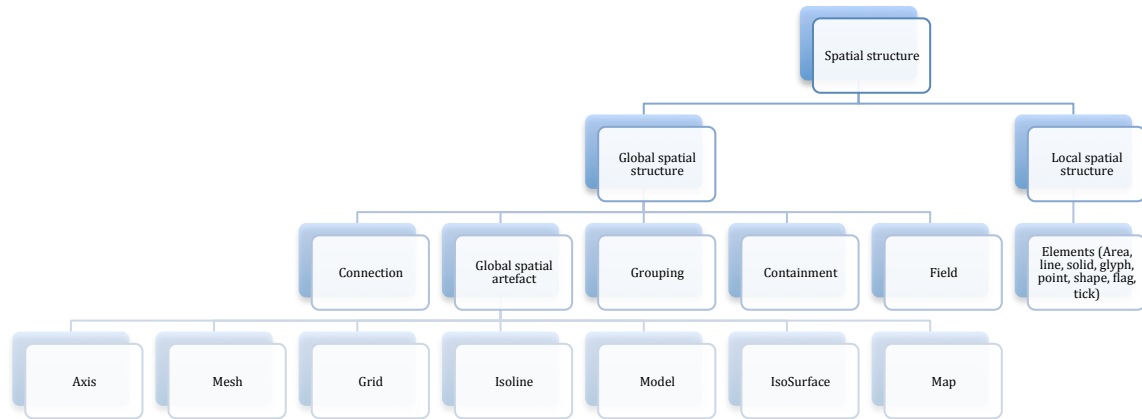


Figure 24. Types of display space according to Nesbitt [2006]

When observing Nesbitt’s categorization for the local spatial structures, there are significant similarities to those characteristics that he calls spatial properties. However, with spatial structures concepts like a line, a point or a shape are considered in the context of the entity.

In graphical user interfaces spatial structures are a common and much discussed theme. Especially when reflecting the taxonomy onto graphics, the structural elements in Nesbitt’s chart can be seen to bear significant resemblance to the elements identified in Gestalt psychology. This is no coincidence as the law of prägnanz also presents the entity (the sum of individual elements) as a dictating factor in interpretation [Koffka, 1935].

Spatial properties are the detailed characteristics defining spatial structures (Figure 25). Nesbitt identifies these information presentation properties as position, scale and orientation. Though the definitions of spatial properties are somewhat overlapping with those concerning spatial structures their slight differences are explained in an example about a scatterplot: “in the scatterplot the position of points is used to convey information. This information is interpreted in terms of the abstract space defined by the [spatial properties of] x and y axis”, whereas “a group of points in the scatterplot can be considered a more global spatial structure” [Nesbitt, 2006]. In other words, spatial properties define the elements within the layout.

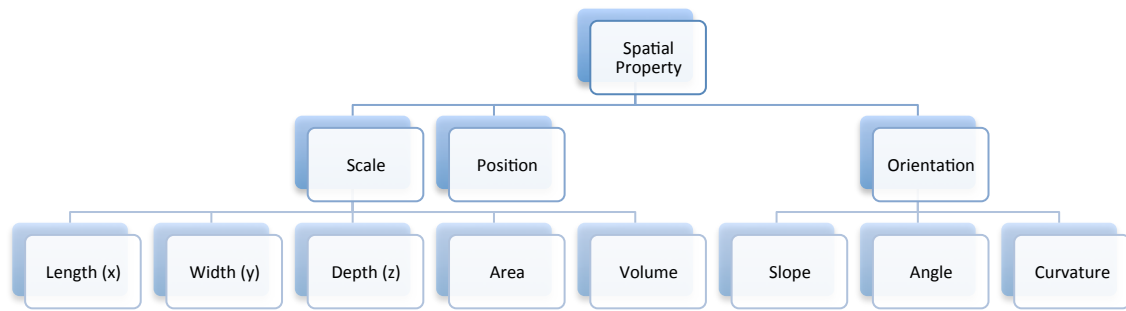


Figure 25. The types of spatial properties by Nesbitt [2006].

The role and importance of the layout in the haptic design is well examined and described in the paper “On tangible user interfaces, humans and spatiality” by Sharlin et al. [2004]. Though the focus is on tangible interfaces, which by definition¹ can be slightly different from haptic interfaces, the findings and recommendations are applicable to the design of haptic interaction in general. The key idea in the paper is about taking advantage of the human’s “innate ability to act in physical space and interact with physical objects” [Sharlin et al. 2004].

Sharlin et al. present two spatial heuristics that have clear benefit to layout design: the endeavour to match the physical/digital mappings and the unity of input and output space. The given emphasis on these viewpoints is in line with other widely accepted theories about interaction design. The statement concerning the importance of the physical/digital mappings get support for example from Norman’s principle of mappings: “... taking advantage of physical analogies and cultural standards, leads to immediate understanding” [Norman, 2002]. He also indirectly comments on the idea of combining input and output space along his principle of feedback: “Imagine trying to talk to someone when you cannot even hear your own voice”. When applied thoughtfully, Sharlin et al.’s two heuristics are likely to improve intuitivity and communication power of the haptic interface.

The affecting factors of layout also appear on user interface guidelines such as on iOS’s “Use Layout to Communicate” [Apple Inc. 2016]. Though discussing mainly graphical user interfaces, some of the iOS guidelines (list below) can be applied directly into the dimensions of multimodal spatial structures and properties. The translated recommendations for the spatial structures and properties of haptic design could be to: give important content or functionality greater dimensions by using haptic weight (for example through friction); place those points/areas of interest spatially to the beginning

¹ According to Raisamo and Rantala [2016], tangible interaction relates to “passive haptics” a.k.a. the haptic sensations from physical properties of an object.

of interaction; use a grid, grouping and alignment to communicate hierarchy and contextual connections; and last but most importantly, make sure the overall spatial haptic layout has a sufficient resolution and spacing for the users to identify the structure of the layout as well as the individual elements.

Use Layout to Communicate in Graphical spatial structure, spatially relevant guidelines by iOS from the section “Use Layout to Communicate” [Apple Inc. 2016]:

- Make it easy to focus on the main task by elevating important content or functionality.
- Use visual weight and balance to show users the relative importance of onscreen elements.
- Use alignment to ease scanning and communicate groupings or hierarchy.
- Make sure that users can understand primary content at its default size.
- As much as possible, avoid inconsistent appearances in your UI.
- Make it easy for people to interact with content and controls by giving each interactive element ample spacing.

5.3.2 Spatial design space applied

In the example case of designing haptic features for a touchscreen keypad, I see the most obvious frame of reference to be the orthogonal display space; a single output field along the touchscreen surface. Subdivided and distorted display space approaches could have potential for a more sophisticated and intricate haptic system, but they do not seem optimal in this given example considering the restrictions of the use in public space. When designing a haptic keypad for a touchscreen kiosk or a vending machine, it is important that the display space presents itself to the user and communicates its boundaries in space from the first contact. The user’s time constraints, lack of experience and varying abilities are likely to restrict the haptic exploration in space, which supports the use of a simplified haptic space – an orthogonal layout.

In the interface of a touchscreen kiosk the idea would be to use the haptic modality as an assistive and supportive feature. Therefore, it would be important to avoid contradicting messages from different outputs. In terms of multimodality, the

orthogonal approach with haptic features supports the commonly used 2-dimensional output of graphics, and can be expected to follow simple conventions such as haptic events occurring when the concrete interaction surface is touched.

The spatial structure of the keypad layout is the same in most cases that I have documented within this thesis. The division of the functional segments is easy to identify, because of its common grid-like layout. The metaphors encoded within the spatial haptic design would benefit from utilizing the culturally conventional layout of order from small to large along reading direction (left to right and top to bottom). The first key could be expected to be number one since no countable number tends to start with a zero and thus also most keypads have number one as the first digit.

When thinking about the interaction event, after the user has found the interaction surface a.k.a display space and identifies its borders the user identifies haptic elements in space (area, line, solid, glyph, point, shape, flag, tick). User recognizes that they form patterns: the elements of local spatial structures form a composition of connections, grouping, field, grid based on the elements' similarities and differences. There is a sensible pattern on the screen: a keypad grid. The user does not necessarily have to interpret the meaning of each individual element separately, but realizing that there is a grid is enough to give the user an idea of what each interaction element (button) should or at least might try to communicate. Based on the users existing knowledge (mental model) of the meaning of directions he can make the first assumptions on what would be the likely numerical order of elements and how the concept of moving forward and backward could have been applied to the keypad context.

Considering the interaction process (first choosing the number and then either removing or accepting the selections), it could be logically justified to place also the action keys onto the last row of the keypad. The reverse/delete button should be on the left as a reference to a past state and the accept button on the right to offer a closure to the process. However, how to place the bottom row's 0-button in terms of the action keys can easily be debated on. To clarify the order of especially these three buttons, I find the most intuitive spatial solution to be the use of variation in button area (Figure 26). If, for some reason, the grid cannot be altered to allow action keys to become larger in space, I recommend utilizing different kinds of haptic clues from other haptic design spaces.

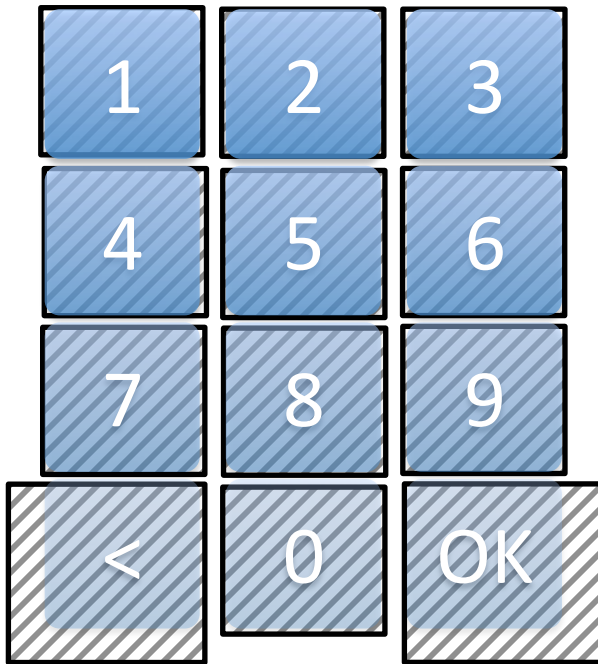


Figure 26. Example of building distinction through variation in button area.

5.3.3 Temporal design space

“Designing temporal metaphors is analogous in many ways to the design of music.” [Nesbitt, 2006]

The effect of time enables changes of state, which for an essential characteristic to most interface design. These changes of state and continuity form the fundamental action-cycle in interaction and are perceivable through all senses. By using spatial and direct properties with temporal variation, time enables perceptions such as the notion of *duration, rate, frequency, rhythm and sense of movement*, all of which carry both intuitive meanings as well as potentially learnable messages concerning the on-going actions. [Nesbitt, 2006]

Different sensory stimuli take different amounts of time for the forming of a perception due to both physiological and cognitive factors. Though the timeframe required to establish that perception might differ between modalities, the brain has a natural tendency to link modalities together. This natural communicativeness of temporal

metaphors can be explained with the Gestalt principle of common fate: similarly moving or changing elements are seen to belong to the same group [Koffka, 1935]. Due to this powerful perceptual tendency, temporal metaphors should never be overlooked.

While temporal fluctuation concerns all modalities and can intuitively entwine them, it can also separate modalities from one another and cause conflicts in interpreting meanings. A typical example of this is the effect of time delay on video image and sound: watching a video of people discussing can feel almost crippling for understanding if the words come with a long delay.

Another significant factor in interpreting information and interaction in a temporal space is the processing speed of each sense. Due to the fact that processing of touch sensation is slower than that of vision, designers ought to be aware of the possibilities of the congruence effect [Martino and Marks 2001], especially when designing haptic features along with graphical user interfaces. By this I mean, that even when no temporal features have been designed into the multimodal interface, the user–technology encountering event has temporal aspects to it, because of the physical and mental processes occurring within the human counterpart. Section 5.3.5 gives more insight to this congruence effect.

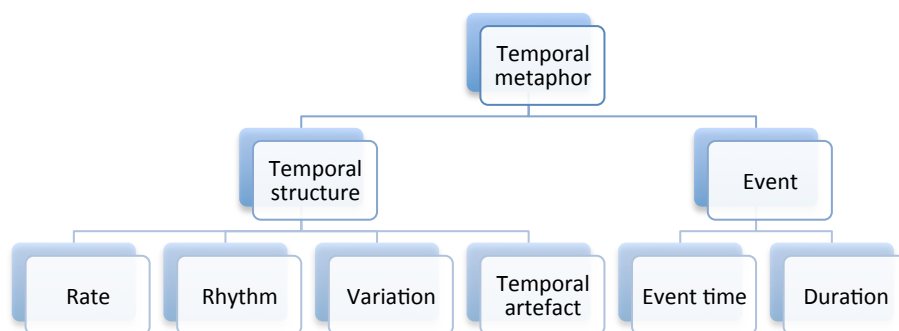


Figure 27. The division of temporal metaphors by Nesbitt [2006].

Temporal metaphors can be observed from two points of view: the temporal structure and time factors of the event (Figure 27). In addition to these viewpoints, the occurring events can be considered within a certain display time. Nesbitt does not consider display time as part of design space, but explains it rather as the natural environmental setting, such as tempo in music, in which the event takes place. Its influence is significant, but not designable to the same extent as temporal structure and the event itself. [Nesbitt, 2006]

In temporal metaphors the strongest communication power is in the changes of single *events* (Figure 28). The clues are embedded in the event time (“time at which event occurs”) and the event duration (“length of event”). Nesbitt categorizes four types of events: *movement*, *display space*, *transition* and *alarm*.

A movement event is a change in direction, velocity or acceleration. It concerns display space and most commonly manifests itself as scale (change of size), rotation (change of position) or translation events (change of property). Display space events have a strong bond to user’s actions. The most typical case is the navigation event in which the system responds by the means of display space design. The transition events cover slow changes to direct properties or the spatial structures. Alarm events do the same more suddenly in a shorter timespan. [Nesbitt, 2006]

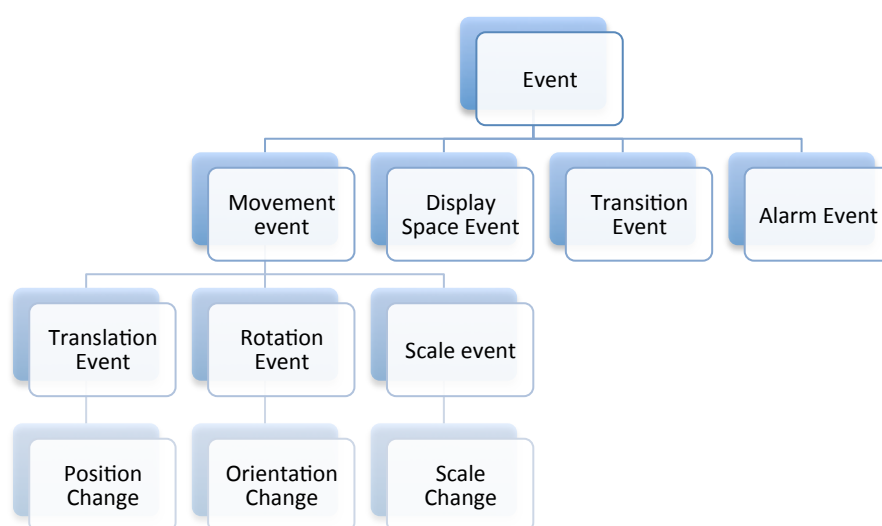


Figure 28. Structure of temporal events according to Nesbitt [2006].

Temporal sequences are often seen as the key attributes to the design of auditory and synthetic haptic icons [MacLean and Enriquez, 2003]. When building haptic sensations for passive touch, temporal sequences are necessary for updating the touch perception. An experiment by MacLean and Enriquez [2003] is a good example of how a passive touch system relying on temporal variation can sufficiently communicate a set of encoded haptic sensations, haptic icons. The used variables were shapes, frequency and force amplitude, out of which frequency appears to play a “dominant perceptual role among a set of time-invariant parameters” [MacLean and Enriquez, 2003]. It is likely

that this conclusion applies accurately only to the design of the experiment device, but, nonetheless, it proves frequency to be a potentially effective variable of haptic design.

Another experiment, conducted by Swerdfeger et al. [2009], set out to explore “Melodic Variance in Rhythmic Haptic Stimulus Design”. Like in the case of MacLean and Enriquez (2003), also in the work of Swerdfeger et al. temporal qualities were an essential part of each of the stimulus variables (rhythm, frequency and amplitude). In the discussions, Swerdfeger et al. summarize the most distinct and communicative variable to be rhythm [Swerdfeger et al. 2009]. This comes as no surprise, after all rhythmic clues have been successfully used through language systems like the Morse code for a century.

Even if no complex information is communicated through haptic events, a simple haptic event can be very meaningful in communicating the status of the system. Chan et al. [2008] studied the possibilities of tactile feedback in a remote collaboration task. In the setting the changing of interaction turn was signalled with a tactile clue, leaving the auditory and visual channels for other uses. The used metaphor is an intuitive one – physically requesting space over others, and interpreting when one’s turn is, from temporal haptic clues. The haptic events of Chan et al’s experiment concerned no movement, but a display space change as vibration’s properties. In other words, the transition notified the changing state of the user’s role through temporal change of direct properties. [Chan et al. 2008]

As interaction time tends to set constraints for the length of haptic interaction, not all haptic sensations are meaningful or even possible to execute. The available time-frame also concerns the synchronization of haptic features to other modalities, but to make multimodality and the timing of haptic sensations even more difficult to design, Oviatt [1999] reveals that “multimodal signals often do not co-occur temporally at all during human-computer or natural human communication” and for that reason, simply temporally overlapping all related visual, auditory and haptic variables is not advised [Oviatt, 1999].

It is possible to place and identify patterns within a sequence of events. These patterns are referred to as the temporal structure. Rate, rhythm, variation and temporal artefacts define temporal structure. In a touchscreen interaction, temporal structure could be examined for example in terms of response time to touch actions, speed of transitions and speed of information flow.

Nesbitt does not explain in detail how rate, rhythm, variation and temporal artefacts can be identified within haptic features, but from his chart models and overall thoughts I

have interpreted the ideas on how rate, rhythm and variation in events can be understood.

The *rate* refers to the “speed of events”. If the change of an individual factor would be considered as an impulse, the rate could be seen as the pulse of the interaction. In a touchscreen interface utilizing haptic output the rate in which the haptic modality is used must consider the physiological limitations of touch perception. If the strength of the stimulus is subtle, the noticeability of it is likely to depend on the rate in which it occurs.

Rhythm is the “temporal pattern of events”. Continuing with the analogy of impulse as a unit of stimulus, rhythm would be an adaptation of the pulse. Along with many other studies, the previously mentioned one by Chan et al. [2008] used rhythm as the main indicator for system status.

Variation is the “deviations in events”. [Nesbitt, 2006] It is an effective feature for communicating an alert or some other significant note.

5.3.4 Temporal design space applied

Leaning on what Oviatt [1999] stated about overlapping multimodal variables, I think the calmness of the interaction should be prioritized also in terms of multimodality. In a graphical–haptic interface such as the given example of the number keypad, some graphical temporal effects should not try to mimic the graphics only for the sake of multimodal consistency. By this I mean that although some aesthetic characteristics such as a graphically animated transitions, might feel important to the overall feeling of the interaction, there is no point in confusing the user with them, unless they can be made to communicate about the process.

In the example case of adding haptic features to a touchscreen keypad of an information kiosk/vending machine, there are three important temporal events in interacting with a touchscreen: scanning and communicating the content; interaction with the interface components; and receiving feedback from the on-going processes underneath the user interface. Though encoding each of these events with different haptic designs would potentially make the interaction more communicative, also touch gestures and their temporal qualities would have to be adjusted to enable touch feedback. This means that if the scanning and exploring for haptic clues of the content is enabled, touch contact alone cannot launch actions, and that there needs to be a separate touch gesture for pushing a button. For this I recommend the using the “click” versus “double-click”

analogy: with a single long touch or a continuous contact stopping on top of a content element the clue of the element would play.

When the user would first lay a hand or a finger onto the touchscreen, the contact could give a mild pulse just to demonstrate its haptic activities. Then once the user identifies the interaction space and the likely structure of the content (Section 5.3.2), the user will want to know what each element in the content signify and do. As explained in the previously in chapter about spatial design space, is likely that the user will assume number one to be the top and leftmost button on the 3x4 –grid and that the button below it is number four and so on. However, in order to confirm the meaning of each button, the user can be expected to want to touch a couple or all of them through in search of clues. For labelling the numbers of the buttons, I would use a rhythmic clue based on single and paired pulses equal to a whole note and a half note (Figure 29).

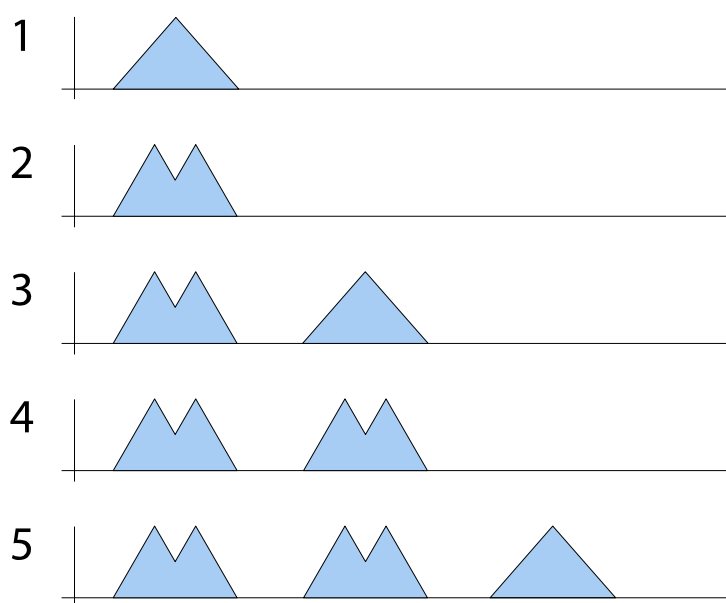


Figure 29. An illustration of the system of rhythmic clues for telling the number in each button. Rhythms for buttons for 1 to 5.

In processes that are important for the user to know, haptic clues should be used to describe the changed state. In most of the current cases, movement event happens as feedback when for example a button is pressed or the system is loading new content. The change on a button is typically indicated with a graphical effect (brief flashing of a different colour or a shadow effect or a sudden growth or shrinking of its size), and loading most commonly presents itself as a circulating ring or a moving progress bar. In terms of haptic effects, movement events could be imitating physical buttons with a subtle clicking feeling or a simple vibration to communicate the temporary change of

state. To separate the feedback from scanning and having clicked/pushed the button, the length of the haptic pulse could be different, but better distinction could still be added by taking advantage of the direct haptic properties of the effect. The loading of information could be made haptic with a wave like vibration that would increase and decrease slowly.

5.3.5 Direct design space

According to Nesbitt, direct metaphors exist between abstract information and sensory properties or as named here: direct variables. Direct variables are the sensory dependent qualities, such as colour, tone and temperature that mainly exist in one sensory domain only. Some exceptions exist, such as the variable of texture, which can be observed in visual, haptic and even in auditory contexts. In general, perhaps the easiest way to distinguish a direct variable is its independent nature from spatial and temporal factors.

In the MS-Taxonomy, Nesbitt fails to give a comprehensive explanation for how to map the direct variables between different modalities. The overall theory of the direct design space is left too incomplete for me to build my work on. Instead of Nesbitt's theory, I choose to present my own approach, which is an adaptation built on his themes.

Direct metaphors are “highly specific for each modality” making them harder to apply in a multimodal context [Nesbitt, 2006]. On the lower levels of Nesbitt's MS-Taxonomy visual, auditory and haptic metaphors are approached individually and no cross-modal context is given. This is because the detailed qualities from each modality do not necessarily have anything in common. However, on the higher level, some type of categorization might support multimodality, while it is possible to match or substitute a direct property of one modality to that of another (Figure 30). Some actual guidelines for combining direct variables in a multimodal environment might exist, but in the context of this work I have not been able to find any sufficient ones.

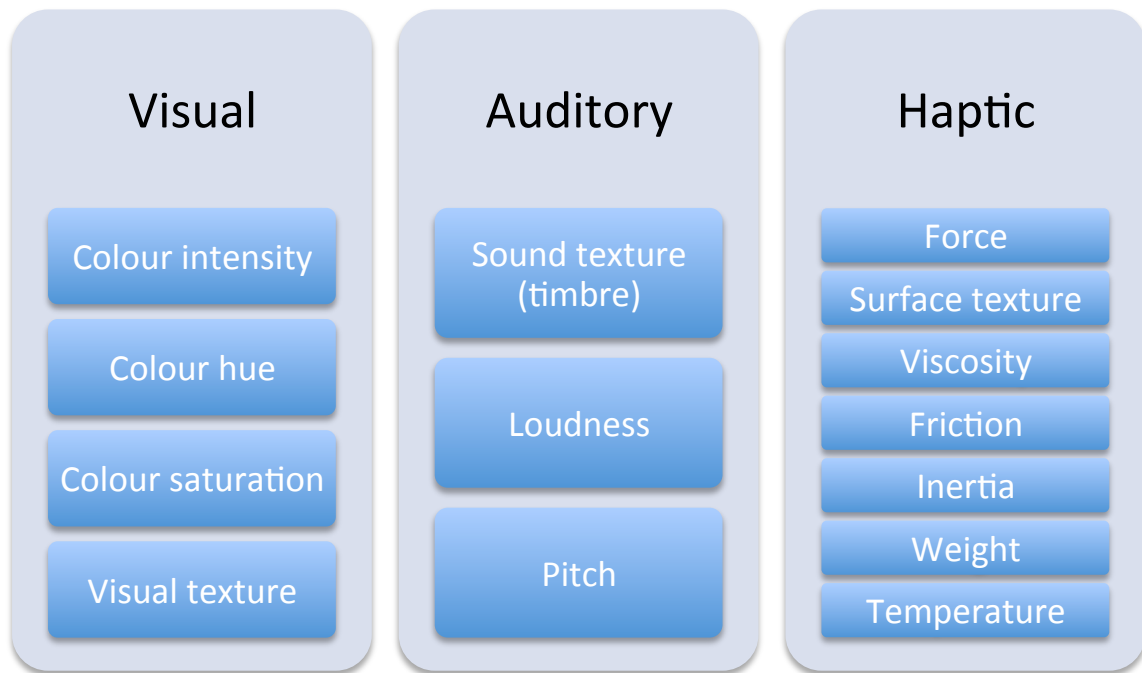


Figure 30. Examples of direct variables within modalities. Nesbitt names also other variables, such as direct visual shape and direct haptic shape, but as they are not explained, they are excluded from this listing. Though it was not mentioned in MS Taxonomy, I also chose to add temperature, since it is a unique feature of touch.

While trying to find studies concerning the combination of some of the direct variables mentioned by Nesbitt, I ran into a paper by Martino and Marks [2001], which discusses the combining of direct variables from the point of view of perceptual psychology. Though the paper *Synesthesia: Strong and Weak* does not concern information technology and therefore gives no interaction design tips, it gives an excellent overview on multimodal perceptions especially in terms of direct variables. [Martino and Marks 2001]

Synaesthesia refers to the entwined perception of unrelated sensory perceptions. This association or a correspondence between the two separate perceptions can be either learned or inborn. Martino and Marks name the two types of synaesthesia as strong synaesthesia (normally inborn) and weak synaesthesia (learned).

Considering the purpose of utilizing haptic direct variables in a multimodal environment it is relevant to discuss the weak synaesthesias. Martino and Marks state about the weak synaesthesia, that: “There is considerable evidence that one can create, identify, and appreciate cross-modal connections or associations even if one is not strongly synesthetic.” Later on they continue by stating: “weak synesthesia is most clearly evident in cross-modal metaphorical language and in cross-modal matching and

selective attention” [Martino and Marks 2001]. By this they mean, that in certain context it is natural to link the behaviour of certain variables together.

Just as analogies between direct variables exist in the real world, it is possible to create them in interfaces to broaden the interaction channel. In the paper “Colour-Temperature Correspondences: When Reactions to Thermal Stimuli Are Influenced by Colour” by Ho et al. [2014] colour-temperature correspondence is studied through assessing if colour and thermal stimuli can trigger crossmodal associations. The study shows that colour and thermal stimuli can trigger crossmodal associations. The study shows that colour influenced the interpretation of thermal clues, but not the other way around. This finding is complemented with a consideration for modality dominance or, as Martino and Marks call it, the congruence effect. Ho et al. explain the effect in their study in the following way: ”... visual information (i.e., a colour patch) might dominate over tactile information regarding temperature that may take longer to process, but has no effect on the semantic information that has a comparable processing time” [Ho et al. 2014].

Martino and Marks [2011] report a similar case in which lightness and vibration are found to have a synesthetic correspondence. Similarly to Ho et al.’s findings, also Martino and Marks concluded that the congruence effect was more significant when vibration was evaluated in comparison to lightness [Martino and Marks 2001]. Therefore, it is good to keep in mind that the impression from one type of modality – especially a haptic one – can unintentionally be affected by another type of direct variable.

Many direct variables go hand in hand with intuitive metaphors that are absorbed from the real world, such as sharp shapes stirring discomfort and soft textures being appealing. However, direct variables make no exception to spatial and temporal ones in their association with the context. This means that the values of hardness, stiffness and size have to be defined according to the optimal properties in a case-specific scenario. In addition to the natural clues of direct variables, the properties of direct variables can also be encoded with an “artificial” metaphor.

5.3.6 Direct design space applied

By now I have given ideas of how to implement spatial and temporal design variants into a haptic touchscreen interfaces. I have described how the haptic interface could present itself to new user, how the layout and number content would translate to haptic features and how the on-going actions could be communicated. To demonstrate the

application of the last remaining design space, I use the action buttons as an example to show how to build character with direct haptic qualities.

The action buttons – one button for erasing and cancelling and another button for accepting and confirming the dialled selections – must stand out from the keypad's number buttons. As explained earlier, the relative button area is an intuitive clue for showing the difference between numbers and action keys, but in case any doubt remains, it would be smart to offer a hint about the function of each action key.

In graphical user interfaces the action keys for accepting and cancelling are often presented with traffic light colour symbols. Out of the direct haptic variables, mentioned by Nesbitt, I propose the use of texture for marking the action buttons. It could be possible to go into details with texture markings and for example match the green coloured “OK” button with a more slippery feeling and the “Cancel” button with a rough texture, while leaving the rest of the buttons somewhat neutral in their type of texturing.

Another way to build up a haptic difference between the two action buttons could be to consider the colour clues of green and red in terms of temperature. This however presents a problem with the synaesthesia, since although red and green could be understood to link to temperatures as red to warm and green to cool, in terms of forward and backward, right and wrong, pleasant and unpleasant, the warm and cold effects can have different interpretations depending on the surrounding culture, environment and simply – the user's own body temperature.

Using force to make the “OK” button “stand” or “push” out more, might eventually be the easiest way to give the task-concluding action button the emphasis it deserves. It would then raise higher than the other buttons, be likely to be noticed from the first contact and be avoided since. With magnetic forces – for example – the “OK” button could be higher and slightly resistant to clicking.

6 DISCUSSION

This thesis aimed to explore the field of haptic interaction in a scenario of using touchscreens in publically placed information kiosks and vending machines. My concern was motivated by the digitalization of physical interfaces, which lead me to question what the options are for ensuring usability for the visually impaired who cannot rely on the graphical interface alone. From this starting point I formulated two research questions:

- (1) *How could touchscreen kiosks utilize haptic sensations to better include visually impaired users?*
- (2) *What would be required for touchscreen kiosks to communicate through haptic sensations?*

In the process of trying to find answers to my research questions, I gradually learned the vastness of the field I set out to explore. The stakeholders and affecting factors were many: public interfaces, the visually impaired, haptic perception, haptic technologies and haptic design, just to name the most important ones. Halfway through my planned processes I realized that a more specific research focus was needed to give depth to the approach. Therefore, towards the end I chose to take a closer look at the design tools of the haptic interaction. As a result I managed to bring together ideas from different sources about how to include haptic design as a part of the overall design of a multimodal interface. I believe the thoughts collected into this thesis to form good background knowledge for interaction designers (novice to haptic modality) to start their work on haptic interfaces.

In this chapter I will briefly collect together the main findings of each section and summarize of the overall findings.

As the user interfaces on publically serving information kiosk and vending machines are changing from physical buttons to touchscreen interfaces, an important experience is disappear. This is the aspect of touch feedback. Though information presentation has gotten many new possibilities due to the flexibility of using adaptive graphics instead of physical buttons, the change comes with a price – especially to those who have difficulties seeing.

The visually impaired consist of a wide range of different visual impairments. From full blindness to colour blindness each sub-segment has its own specific requirements for accessibility. While the single largest group of visually impaired is the people (especially the elderly) who have defected vision, but can see to some extent, I found it best to focus on interface concepts that would not just try to create an independent haptic interface, but to build on the existing conventions of the current graphical interfaces.

Though there are many kinds of interfaces in kiosks and vending machines, their usage situation is often the same: a user with very little expertise in the interface must navigate through the system under some kind of a time constraint to complete a task. Due to the time limitation and the varying skill and ability levels of the users the interface must interact clearly and consistently throughout the interaction process. In terms of haptic design this means that the interaction must be made approachable and simple enough for most users to follow.

Though haptic perception consists of different bodily feelings, the most commonly discussed ones are the kinaesthetic and tactile sensations. The kinaesthetic sense monitors the body's movement through muscles and joints, and the tactile sense refers to the skin's abilities to identify qualities of skin contact, such as temperature, pressure, pain and vibration. In trying to understand the affecting factors of haptic sensation this division helps to identify which types of physiological components and processes are active.

All touch senses are considered to be general senses; they do not necessarily require much from cognition and therefore they also develop quickly. The downside to this is that haptic resolution is rarely very high with people who can rely on other, more versatile senses. From the design point of view, other major challenges with the sense of touch have to do with the body's adaptation to situations, that makes sensitivity to haptic stimuli variable. Therefore, as an information channel haptic senses can be quite demanding to design. By ensuring that the responses are fast and that the intensity and stimulus type varies to suite each user, it is possible to produce noticeable haptic perceptions.

There are many ways to transmit haptic sensations as a part of a user interfaces. The main division of the techniques is based on the two types of touch senses: the kinaesthetic that is stimulated with force feedback devices and the tactile displays that are about creating sensations onto the perceiver's skin. Almost all haptic interfaces require contact with the body and an intensity to exceed the threshold of those sensory receptors that are aimed to be stimulated.

In touchscreen interfaces, adding haptic features would almost inevitably mean an exclusion of force feedback a.k.a. the stimulation of the kinaesthetic sense, because of the dimensional constraints of a flat screen. Adding an interaction tool, such as a pen or a wearable device could enable larger motional sensations, but in practise loose parts can be difficult to maintain in a public usage context. Therefore, a combination of a graphical user interface with a tactile display would be a more evident solution. With such a device touch sensations could be enabled with vibration or friction by linear motors, voice coils or electrostatic vibration; or clicking feelings with solenoid; or in the near future even by producing three-dimensional surface shapes with organic surface materials such as ferrofluid.

Whatever the choice of execution might be, it is likely that the role of the haptic modality would be assistive and supportive rather than primary. Due to the fact that most visually impaired users who get in situations to use public touchscreen devices can navigate with their vision to some extent, but could benefit significantly from having narrative touch feedback – as if using a physical interface where action buttons are clearly touchable.

Due to the likely coexistence of graphical and haptic design, the guiding thoughts for the design of haptic features should consider multimodality as a baseline. Therefore, the division of design spaces into spatial, temporal and direct variables offers a good approach to comparing and developing different modalities along with one another. This multimodal design theory helps to identify design features that can be used for building semantic meanings and consistency throughout the user interface.

Though this division has good points to it, the challenge is that it is lacking strict definitions. Perhaps if observed from the point of view of physics – analyzing and comparing wave lengths and so on – it would be possible to find even better matches in multimodal design. However, as not all aspects and mechanisms of touch perception (nor any other perception) are fully understood, scientifically calculated design does not necessarily match the designer's intuition for what is good design.

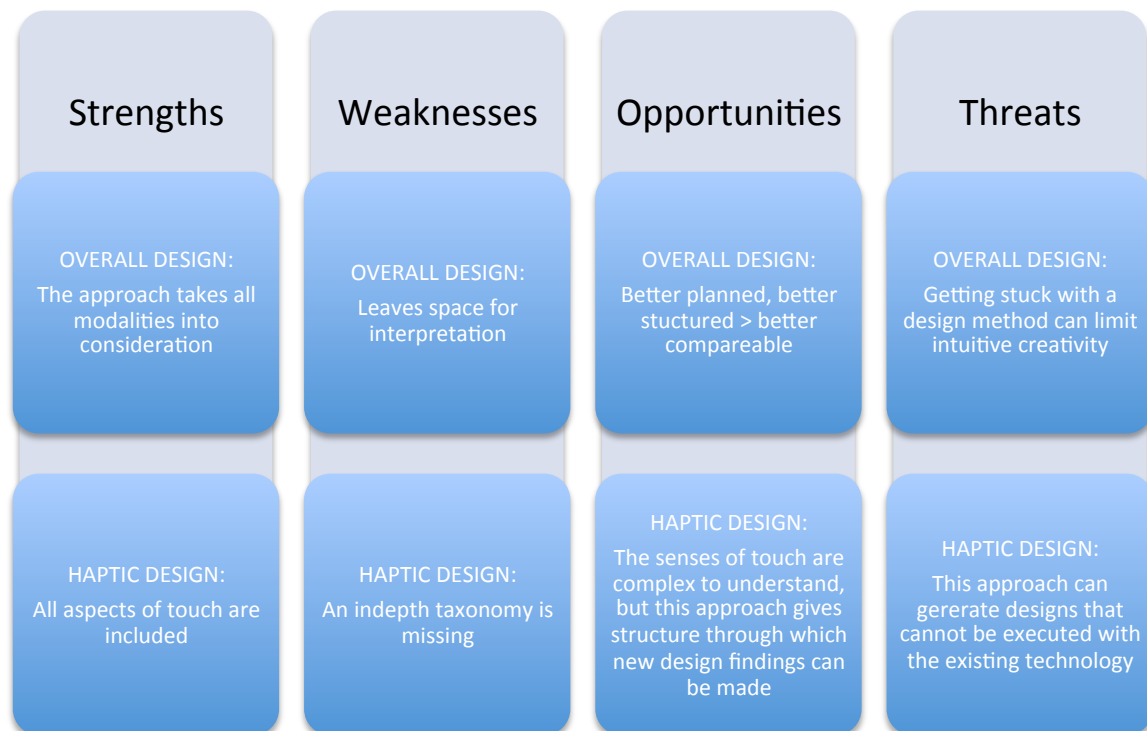


Figure 31. Points about the multimodal design space theory collected under the themes of a SWOT analysis.

As I produced a light theoretical implementation of the haptic design principles along the explanation of the theory, I made some findings about the adaptability of the theory (Figure 31). I conclude that the overall method is sensible and adaptable to many – if not all – contexts, but that in order to do so, the designer must be aware of the many aspects of haptic design. Applying the thoughts of design spaces requires creativity, dedication and a systematical approach to compensate the lack of strict guidelines.

I have no doubt whether haptic feedback can be widely implemented into touchscreen kiosks in the future. To do so requires the right technical execution that responds to the needs of human touch perception with a systematic logic of information encodings. Once well design and executed, haptic features will make the interaction experience more user-involving.

7 CONCLUSIONS

In this thesis I set out to investigate the possibilities of utilizing haptic sensations in touchscreen kiosks to better include visually impaired users. The focus group of the visually impaired and the public context of the interface type formed the direction of my work, but the emphasis fell on identifying the requirements for haptic interaction. I explored three major areas related to the case. These areas are the senses of touch, haptic technologies and haptic design theory. Throughout this thesis I reflected the context of the original interface dilemma (public touchscreen devices and visually impaired user) onto the discussed matters.

My research shows that haptic sensations have great potential for communicating information. Haptic sensations do not necessarily require a great deal of learning since many familiar real-world sensations can be translated into interfaces. One of the major challenges is the flickering nature of touch; sensitivity to stimuli can vary significantly depending on both internal and external factors of the perceiver.

Appearing in the reference materials, another hindering factor in haptic interaction is the technical execution of the stimuli. Though new technical innovations are being made, the complexity of touch as a sensation challenges designers in composing computed sensations that are both smooth and clear.

If however a suitable interaction scenario, such as a simple task of dialling a number series through a software keypad, was to be designed with haptic features, a systematic approach to design is advisable, since the result is almost always multimodal and complex. My research indicates that, an approach considering the entity of multimodal interaction by identifying the repeating elements in spatial, temporal and direct design spaces seems to offer a fluent way to compare and match all types of sensory perceptions. This taxonomy with its subdivisions could help designers to better understand the possibilities for creating meanings within haptic features.

The main contribution of this thesis is the discussion about haptic design within multimodal design theory. Within the search for references only few similar discussions came up and therefore, there still seems to be a need for more research within this field. Though within this work the approach was briefly evaluated in theory, applications of it are required to fully analyse the usefulness of design space division in practice. However, I believe the collected notes of this thesis to work serve as a comprehensive introduction for interaction designers interested in exploring the field of haptic design.

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