OPPORTUNITIES AND CHALLENGES OF TOUCH INTERFACES

Analysing mobile usability with heuristic evaluation

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ABSTRACT

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Opportunities and Challenges of Touch Interfaces
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The objective of the thesis was to provide an overview of the usability of the current touchscreen mobile devices. The thesis answers to the following questions: Why touch? Which new possibilities and challenges do touchscreen interfaces incorporate? Are touch interfaces really “intuitive” and “natural” as they are often claimed to be?

In the empirical part of the thesis, user interfaces of four different mobile devices and their operating systems are analysed using heuristic evaluation in hardware, operating system and application levels to measure their usability. The selected set of heuristics is a modification of Nielsen’s heuristics adapted for touchscreen mobile devices. The evaluated operating systems provide an overview of operating systems used in Finland and include Android, Windows Phone, iOS, and Sailfish.

The results indicate that currently the greatest usability violations are low visibility of objects, actions and options; lack of undoing and redoing actions; and not providing help centered on the user’s current task. Problems in visibility are mostly related to the usage of touchscreen gestures and that using gestural interactions is not properly guided to the user.

Key words: touchscreen, mobile, usability, user interface.

CONTENTS

1 INTRODUCTION

Usage of mobile devices has grown rapidly after 2007 when they were incorporated with easy-to-use touch interfaces. In addition, the amount of third-party applications has expanded and mobile devices have become small computing devices capable of a great amount of tasks. People also find using touch interfaces fun and engaging.

In addition to the benefits, touch interfaces have posed new usability challenges. Currently, platforms and operating systems have solved touch-related problems in different ways, and there are no common standards yet.

Firstly, I will present the qualities of touch interfaces in general. I will provide a brief history to understand what made touchscreen mobile devices successful and to show how rapidly mobile usage has grown. Secondly, I will analyse the terms “intuitive” and “natural” in detail for gaining a deeper understanding of the characteristics of touch interfaces. Thirdly, I will present the opportunities and challenges that touchscreen mobile devices bring within.

Finally, I will analyse usability of four touchscreen mobile devices and their operating systems using heuristic evaluation. Whereas mobility has brought new challenges to the traditional usability evaluation methods, the selected heuristics are modified to take considerations related to mobile environment and ergonomics into account.

2 BRIEF HISTORY OF TOUCHSCREEN MOBILE DEVICES

To begin with, the term “mobile device” needs to be defined. Merriam-Webster Dictionary (2015) describes the adjective “mobile” as “capable of moving or being moved”, which indeed is the core functionality of the devices and the reason why they are made both compact and lightweight (Janssen, 2015). Oxford Dictionary (2015) sums up the term of mobile device as “a portable computing device”. Computing abilities of the devices have been under constant development and their advances have undoubtedly affected to their increased popularity in the consumer market.

In the following chapter, I will introduce the near history of how the mobile devices became “smart” by manufacturers incorporating them computing abilities.

2.1 PDAs

In the 1980s, personal digital assistants, PDAs, were brought to the market (Hoober 2014). They were handheld computers usually equipped with web browsing and email abilities, and personal organizer including features such as calendar and notebook. Some included third-party applications such as games. PDAs had touchscreens that were typically used with a stylus, and typing on them was based on handwriting recognition, stroke recognition or a small keyboard. (Arokoski et al. 2002, 27–28; Wiggins 2004). Some PDAs even included voice recognition abilities (Wiggins 2004). Although PDAs became indispensable for a large working population, they remained largely uncommon in the mass consumer market. Today, they are largely forgotten with the overwhelming success of smartphones. (Hoober 2014.)

2.2 Smartphones

The term “smartphone” was first introduced in 1980s, referring to a telephone enhanced with computer technology, but entered the common usage only after the release of first iPhone in 2007 (Huddleston 2012). The iPhone was introduced in 2007 and, contrarily to the previous attempts to launch devices with comparable features, succeeded in the

mass market. It brought many existing technologies together bettering its mobile competitors in terms of user experience, web browsing, and after the launch of App Store in 2008 on extensibility of applications as well. (Rieger 2012, 56; Fogg 2012.) One of the key features of the iPhone was the touchscreen that did not require using a stylus and that supported multi-touch gestures.

Contrarily to PDAs and PDA phones, the iPhone was designed to be a media consuming center. Fast networks that speeded up browsing the web and popular applications such as Facebook and Twitter, which would work well in the mobile context, also helped to turn consumers towards buying touchscreen mobile devices.

iPhone turned out to become a market defining product for the new generation of smartphones as other device vendors followed its touchscreen-based functionality (Fling 2009). In September 2008, Google answered with Android which quickly became the most popular mobile operating system. Microsoft released Windows Phone in 2010 (Rosoff 2015) and Jolla released Sailfish OS in 2013. Worldwide, in February 2015, Android was having the biggest share of usage with 60.75%. iOS was the second with 23.14% and Windows Phone ranked noticeably lower with 2.28%. Sailfish covered a notably smaller part which did not appear in the worldwide listings at all. (StatCounter 2015.)

2.3 Tablets

Before 2010, no vendors had succeeded in bringing tablet-like devices to mainstream usage. The iPad was launched by Apple in 2010, and by having both strong ecosystem on its back and being accompanied with an interface and applications already familiar from iPhone, turned out as the first tablet computer to create rapid and massive sales. Soon after the release of the device Apple had sold a million iPads, which happened signifigantly faster than the sales of first-generation iPhones (Goldman 2010). Android rejoined the market with commercially viable tablet operating system more than six months later (Huddleston 2012). Microsoft provided Windows for tablets, and Sailfish was also designed to be suitable for tablet devices (Roppola 2014).

Whereas tablets can be categorized as mobile device based on their portability and touch-based operating system, they are mostly used at home connected to a stable wireless network (Müller, Gove & Webb 2012, 9). It is also notable that shipments of tablets declined for the first time in the fourth quarter of 2014. This shift away from tablets may likely be affected by the growing size of smartphones and increased sales of phablets – smartphones that portray screen size close to a small tablet device. (Kharpal, according to Mawston 2015.)

2.4 Growth of mobile usage since 2007

Flurry Analytics report in August 2012 concluded that the rate of iOS and Android device adoption had surpassed that of any consumer technology in history. Compared to recent technologies, touchscreen mobile device adoption has been ten times faster than that of the 1980s personal computer revolution, two times faster than that of the 1990s Internet boom, and three times faster than that of the recent social network adoption. Overall, Flurry estimates that there were over 640 million iOS and Android devices in use during July 2012. (Farago 2012.)

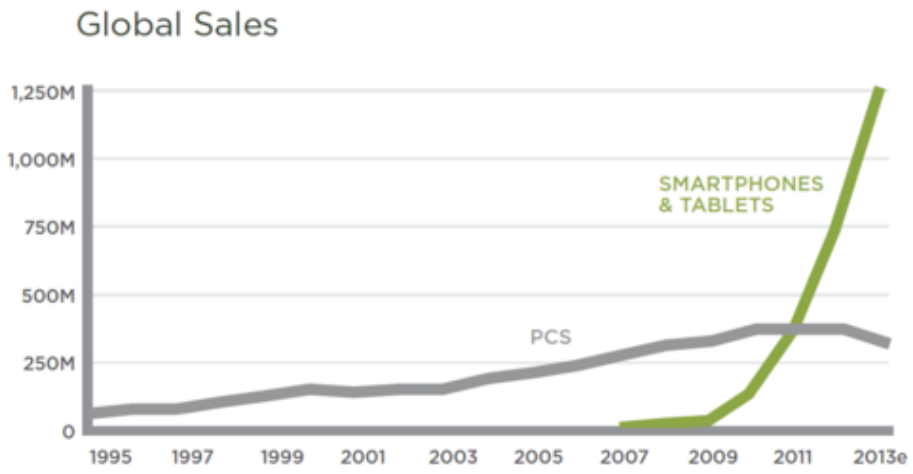

FIGURE 1. Global sales of smartphones, tablets and PCs 1995–2011 and estimation for 2013 (Evans, according to Gartner, IDC & Enders Analysis 2013; Voorhees, according to Wroblewski 2013)

Especially smartphones can be described as a disruptive technology – one of the technologies that comes radically and changes the world. Touchscreen mobile devices have created a massive shift in how people interact online (Huddleston 2012).

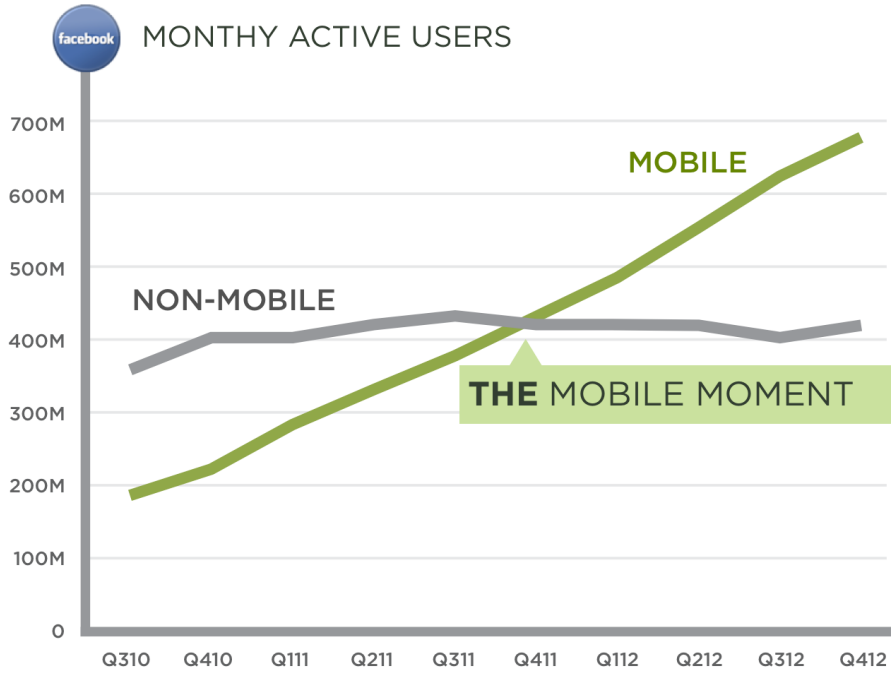

FIGURE 2. Mobile usage of Facebook surpassed non-mobile globally at the last quarter of 2011 (Wroblewski 2013d, according to Constine 2013)

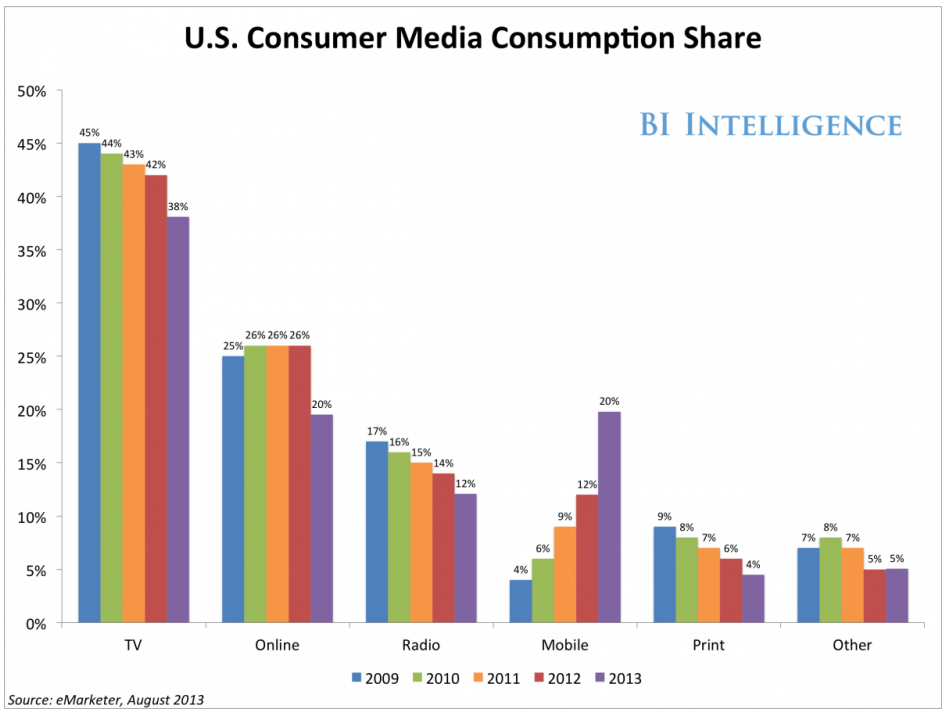

FIGURE 3. In the US, in 2013 consumers were spending as much time on mobile as they were in the online category including all activity on desktops and laptops (Danova 2014, according to BI Intelligence)

Especially global smartphone adoption is estimated to grow massively in the coming years, particularly in developing markets (Almazán & Sitbon 2014, 2). People who were not able to afford a desktop or laptop computer can now get reasonably priced mobile devices with increasingly affordable data plans. In addition, mobile network connections are constantly getting faster and more extensive. (Wroblewski 2011, 11.)

3 ARE TOUCH INTERFACES INTUITIVE AND NATURAL?

The term “user interface” refers to the space where interactions between humans and machines occur (Kuo-Ying 2009, 1). Touch interfaces are often described as intuitive and natural without defining the terms in detail. What do these qualities exactly mean?

According to Raskin (2000, 96) the term intuitive originally meant that the user would have the knowledge of using the interface instinctively, without prior exposure to the concept, without having to go through a learning process, and without having to use rational thought. In reality, interfaces that users report intuitive are mostly ones that have been designed so that users can take their skills from one situation and re-apply them to a new situation (Kurtenbach 2011, 155).

Touching things can be considered natural for humans. In physical world it is the way we manipulate things and explore how objects feel and behave. Compared to desktop interfaces, touch-based interfaces do not require using a mouse or trackpad and cursor which form a layer that separates the interface and the user. Whereas using a mouse as input is easy to learn, using fingers is something humans have already learned.

Practically, both terms intuitive and natural equate to “very easy to learn”. Whereas intuitiveness and naturalness can be hard to define, learning time can be easily measured (Raskin 2000, 96). Therefore, when naturalness and intuitiveness are measured by learning time of input, touch interfaces outperform desktop interfaces. Therefore, it can be considered that manipulating touch interfaces directly is more intuitive and more natural than learning to use interfaces with a mouse and cursor (Nielsen 2012).

To conclude, touching things is intuitive and natural for humans, and various real-world activities and conventions can be utilised in touch interfaces to make their usage more intuitive. Still, touch interfaces should not be expected to feel absolutely intuitive and natural to all of the users. Even they have elements from real world, they cannot work in a similar way as they are operated behind a glass screen. Using touch interfaces therefore still requires going through a learning process.

4 OPPORTUNITIES OF TOUCH INTERFACES

Compared to desktop interfaces, touch interfaces have provided new ways of interacting with computing devices. What kind of input type touch is in a bigger context of interfaces, and what are the current conventions common to all touch-based operating systems?

4.1 NUI – Natural User Interface

Several authors have concluded that use of different human senses overall is becoming more and more common in the field of computers (Clayton 2012; Alur, Jumde & Shrivastav 2014). These interfaces that mimic user's real world behavior are called Natural User Interfaces, NUIs (Petersen & Stricker 2009; Clayton 2012). NUIs are based on inputs such as human touch, vision, voice, and motion, and therefore help bridge the gap between real and digital world (Ranganathan 2012). The various input options available in mobile devices are a part of this trend (Kaushik & Jain 2014).

It is still important to take into account that elements of Graphical User Interfaces, GUIs, including windows, icons and menus (Myers 1996) are still widely used in touch interfaces. The major strength of a GUI is visibility, and that all the possible actions can be made easily discoverable through the menus. In conclusion, it is not useful to categorise interfaces strictly as GUIs or NUIs – interfaces can have elements from both.

4.2 Direct manipulation

The term "direct manipulation" was first introduced by Ben Shneiderman in 1974 to describe an interface design strategy consisting of three important components: visual representation of the objects; visible and gestural mechanisms for acting upon these objects; and immediately visible results of these actions (Cooper 2007). At the time, direct manipulation was a step forward compared to manipulating computers with command-line commands. Shneiderman concludes that direct manipulation offers a satisfying experience of operating on visible objects, where computer becomes

transparent, and users can therefore concentrate on their tasks. This manipulation, however, was still done with a mouse cursor. (Shneiderman 1983.)

Today, it can be said that touchscreens take direct manipulation to another level. Users can simply touch the item they want to manipulate right on the screen itself instead of using a mouse and cursor (Saffer 2008). This direct engagement with the onscreen objects has claimed to be one of the key ingredients in the success of touchscreen devices. It is also the reason why mobile interfaces have to take physical properties, such as how objects feel and behave, into account (Clark 2012, 289). The existing touch interfaces have therefore employed concepts such as rigidity, velocity, relative scale and inertia of the objects (Jacob et al. 2008).

4.3 Touch gestures

In the mobile context, touch gestures can be defined as movements that are conducted with a finger on the screen surface. They allow users to manipulate objects, navigate on the screen and perform various functions. Norman (2011) states that gestures are becoming the standard way of moving material around on multi-touch screens.

In the current touch interfaces, gestures are used for replacing buttons, releasing more screen estate, giving more information about their target, revealing additional functionality, and providing expert users faster pathways. Furthermore, they can make user experience extremely effective, engaging, pleasurable and fun. (Kutliroff & Yanai 2014.)

At the moment there are a handful of touch gestures that are commonly used across platforms (figure 4).

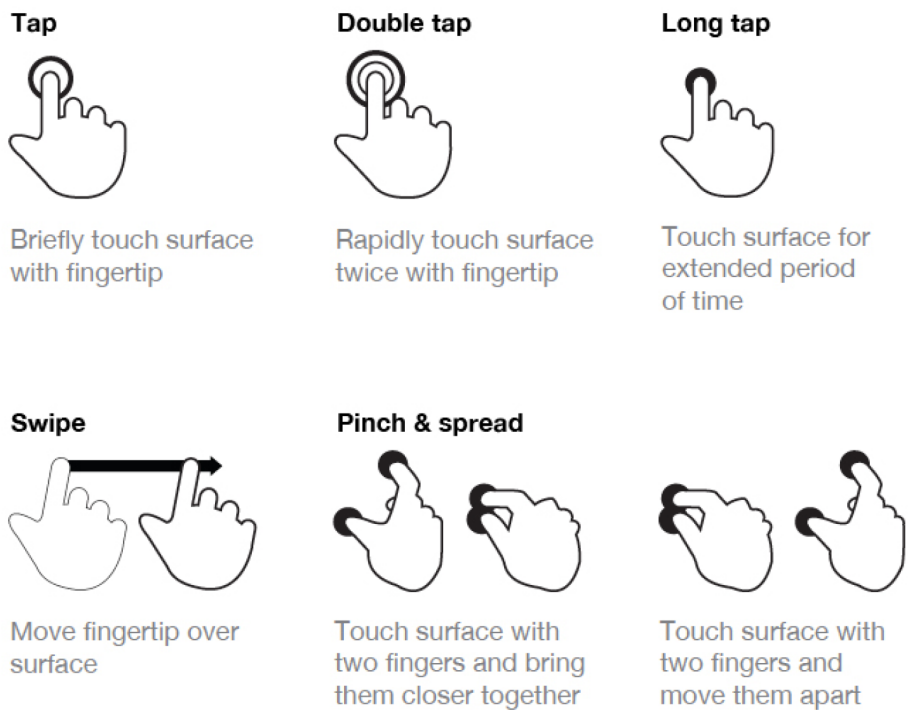

FIGURE 4. Gestures that are commonly used across platforms (Clark 2012; Wroblewski 2010, modified)

Most commonly, tap is used to manipulate buttons, icons and elements. Double tap is used for zooming on mobile browsers, and long tap usually reveals more options or information about the target. Swiping can be used for flicking through the content, for dragging objects, or for performing actions that the user should not trigger by accident (Clark 2012, 323). Pinch gesture is commonly used for zooming objects further away from the user and spread gesture is used for bringing the subject closer to the user.

Nielsen (2012) states that when designing a user interface for a given platform, it is important to emphasise the strengths of the available input. Regarding touch interfaces, usage of touch gestures is about utilising of the smooth glass surface for the best advantage. Touch gestures are especially helpful for overcoming the limitations of limited screen estate. One example of a space-saving gesture is ”pull-to-refresh” patented by Twitter, where pulling down to see more information on the top refreshes the view and shows more tweets if they are available (Mottier 2012).

Directions of gestures also have certain meanings. Direction to the left has been used on desktop keyboard backspace and it therefore relates to deleting. It is also contrary to the reading direction in Western countries. For example, in the email application of iOS 8

(figure 5), swiping either to left or right over the draft message thumbnail reveals different options. Swiping all the way to left, which is hard to perform by accident, moves the draft to trash.

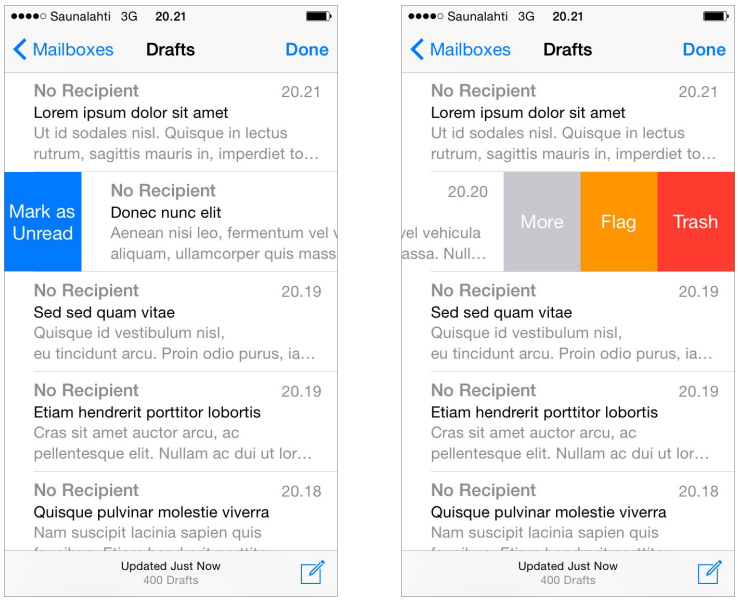

FIGURE 5. Email application of iOS 8

In addition to the currently available gestures there are a number of novel interaction methods that are being researched, such as pressure-based and material-based input options. These techniques on touchscreens are presently in their infancy, but with time and more research they may eventually be adopted. (Duce, Flood & Harrison 2013.)

5 CHALLENGES OF TOUCH INTERFACES

Touchscreen interfaces provide new opportunities, but also set up various challenges. According to Norman and Wadia (2013), these are mostly interaction and design challenges.

5.1 Small screen size

The device being portable requires small size. To maintain portability, mobile devices are obligated to accommodate their various features and tasks into limited estate. Therefore, it is often advisable to strip the design and content down to its essence by tightly focusing on the few tasks that mobile users will need. (Tidwell 2010.)

5.2 Varying lighting conditions

People can use their mobile devices in various places: in the bright sun outside, and in the dark before falling asleep. Especially sunlight makes the contrast of the layout important. It is also good to notice that glossy touchscreens might turn large black areas and backgrounds into a mirror. (Tidwell 2010.)

5.3 Motion

When used on the move, for example when walking on the street or commuting in a bus, text is more difficult to read and touch targets become harder to hit. Therefore, buttons should be large enough to hit, and correcting possible mistakes should be easy. (Tidwell 2010.)

5.4 Touch target size

Apple advises the ideal touch target size to be 44 points, which is around 7 mm (Apple, according to Clark 2012, 308), and Android 7–10 mm. Wroblewski (2013a) recommends 10 mm as default touch target size, whereas the targets may be even larger if the interaction is regularly used.

Microsoft (2015) concludes that different touch target sizes work for different situations. Actions with severe consequences, such as delete and close, as well as the most frequently used actions should use large touch targets. In contrast, infrequently used actions with minor consequences can accommodate small targets.

Taking Fitts' law into account is also important, especially on big screens. In general, Fitts' law describes how long it takes to hit a target, or move an object to a target. In mobile context this means that the smaller the target and the further away it is, the harder it becomes to hit. (Clark 2012, 312.) Therefore, the distance between the touch target and the user's finger should be taken into account as well.

Microsoft recommends 7x7 mm (40 pixels) touch target and 2 mm (10 px) padding as minimum when touching the wrong target can be corrected in one or two gestures or within five seconds. Padding between targets is just as important as target size. (Microsoft 2015.)

9x9 mm (50 px) and 2 mm padding is recommended for interactions where accuracy matters, such as close and delete, where severe consequences can not afford accidental taps. It should be used for targets if touching the wrong target requires more than two gestures, five seconds, or a major context change to correct. (Microsoft 2015.)

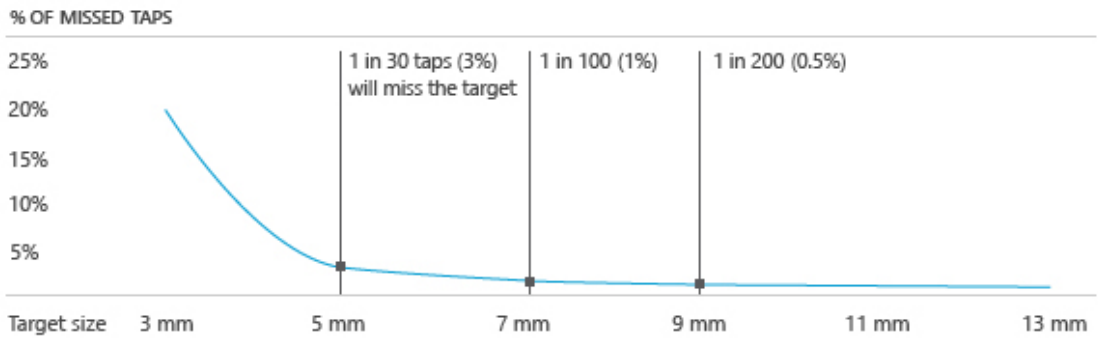

FIGURE 6. Missed taps at different touch target sizes (Microsoft 2015)

Sometimes there might be a situation, where the 7x7 mm recommendation is too large for the design. In this case, Microsoft advises it is acceptable to use 5x5 mm (30 px) targets as long as touching the wrong target can be corrected with one gesture. Using 2 mm of padding between targets is extremely important in this case. (Microsoft 2015.) Clark has found the practical minimum to be 44×30 pixels, as used in the iOS keyboard with smaller padding than 2 mm.

However, it is important to notice that even though the invisible touch area has to be large enough, the visual appearance of the designed button or link can be smaller. Microsoft (2015) recommends the visual size of a UI control to be 60–100% of the touch target size.

5.5 Ergonomics

Ergonomics is one of the most important issues to take into account when designing for the current range of mobile devices. Ergonomics affect to the placing of the software elements in the user interface, such as navigations and content. When designing touch interfaces, it is important to pay careful attention to where hands come to rest. These places change according to the shape, size and weight of the device. (Clark 2012, 298.)

In 2013, Steven Hoober conducted a research to find out how people hold their mobile devices. For two months, the research team observed 780 people using their touchscreen mobile devices on public places such as at the street, in airports, at bus stops, in cafes, on trains and busses in the US and Canada. The team found out that 49% of smartphone

interaction was conducted with one thumb, 36% cradled (holding the phone with one hand an operating with another), and and 15% with two thumbs (figure 7). Even in the cradled mode 72% of the interaction was made with thumb and therefore it can be counted that 75% of smartphone touchscreen interactions are made with thumb. (Hoober 2013.)

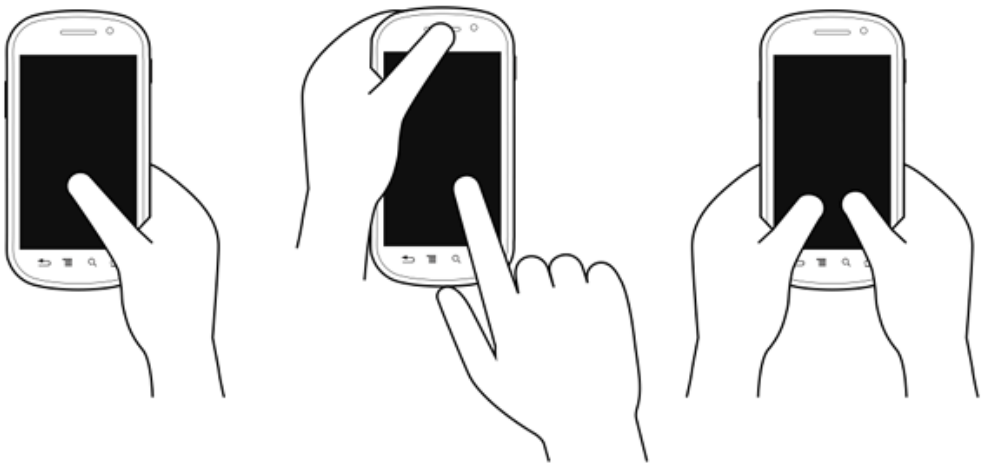

FIGURE 7. Examples of holding a smartphone: with one thumb, cradled and with two thumbs (Wroblewski 2012)

Hoober found out that there were two methods of holding a phone in one hand (figure 8). Some users seemed to position their hand by considering the reach they would need, and holding the phone from closer the top will make the top of the screen more reachable than the bottom. Altogether, about half of the users used their phones one-handedly.

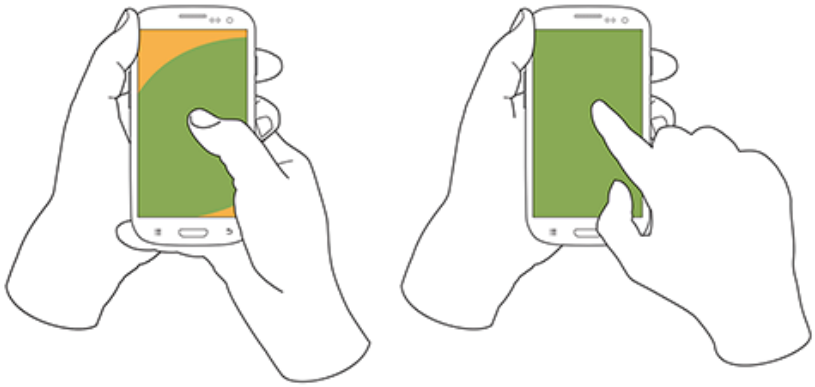

FIGURE 8. The two methods cradling a mobile phone: 72% of interaction was made with index finger and 28% with thumb. Colors indicate the degree of reachability of the areas.

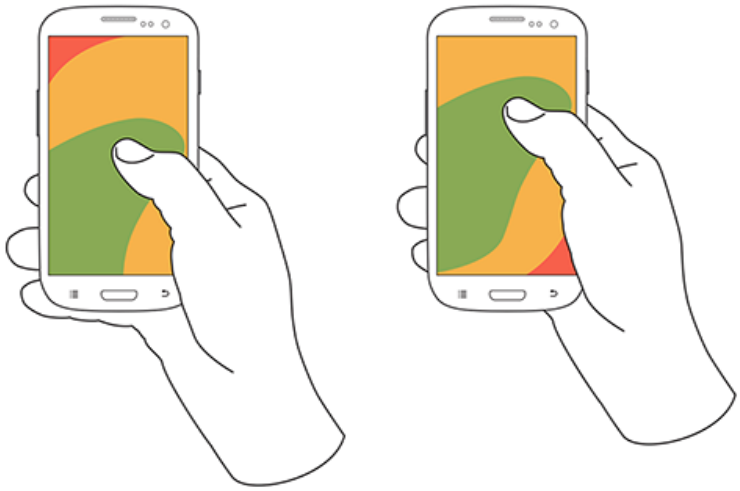

FIGURE 9. Reachability of the two methods of holding a smartphone with one hand – the thumb joint is placed higher in the image on the right (Hoober 2013)

In addition, Hoober observed that 67% of one-handed usage was made with the right hand and 33% with left hand. This does not correlate with the rate of left-handedness in the general population, which is about 10%. Hoober suggests that other needs such as using the right hand for other tasks may drive handedness. The overwhelming use of devices in portrait mode was also notable: 90% of the usage was done in portrait mode and 10% in landscape mode (figure 10).

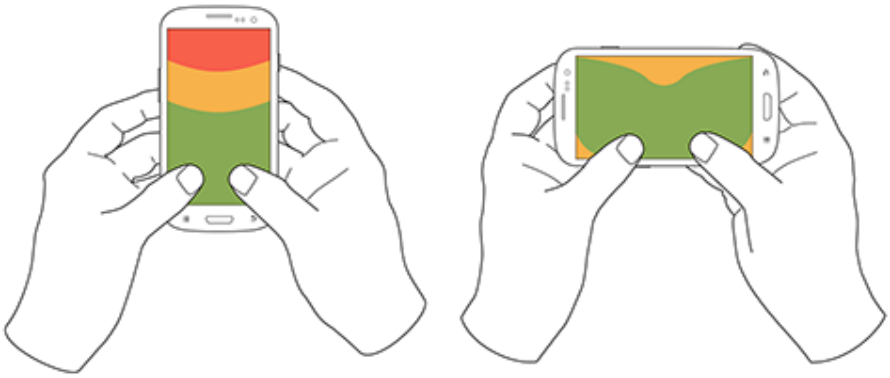

FIGURE 10. Reachability of two-handed usage of a smartphone (Hoober 2013)

Easiness of reaching elements on the bottom is the reason why mobile operating systems and applications often place primary controls there. In addition, this placing prevents the fingers obscuring the screen, which happens when tapping controls on the top.

It is still important to take into account that the study was conducted in public space, whereas it does not include the usage lying on a sofa or in bed, where people can use the devices for long time spans. In addition, the size of smartphone screens has increased after the research was made. On bigger screens, reachability is even more important to take into account (figure 11; picture 1).

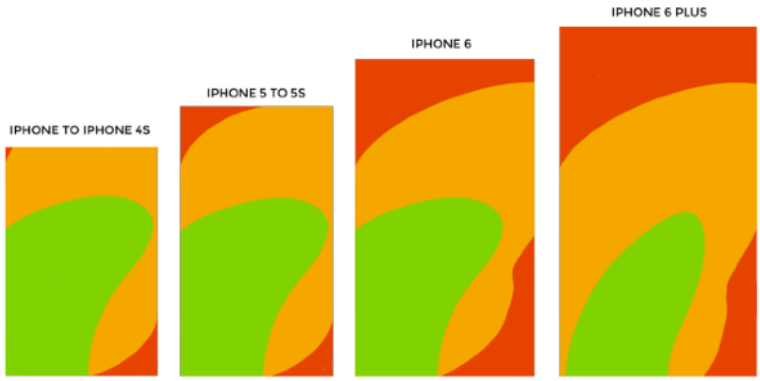

FIGURE 11. Reachability of areas on the latest iPhone models (Hurff 2014, modified)

PICTURE 1. Samsung Galaxy Note 3, one-handed mode (Dambrāns 2013)

Tablets, due to their larger screen size, are held differently than smartphones: one-handed use is less comfortable and two-handed use is more common. The sides of the screen are the easiest to access (figure 13). (Wroblewski 2013c.)

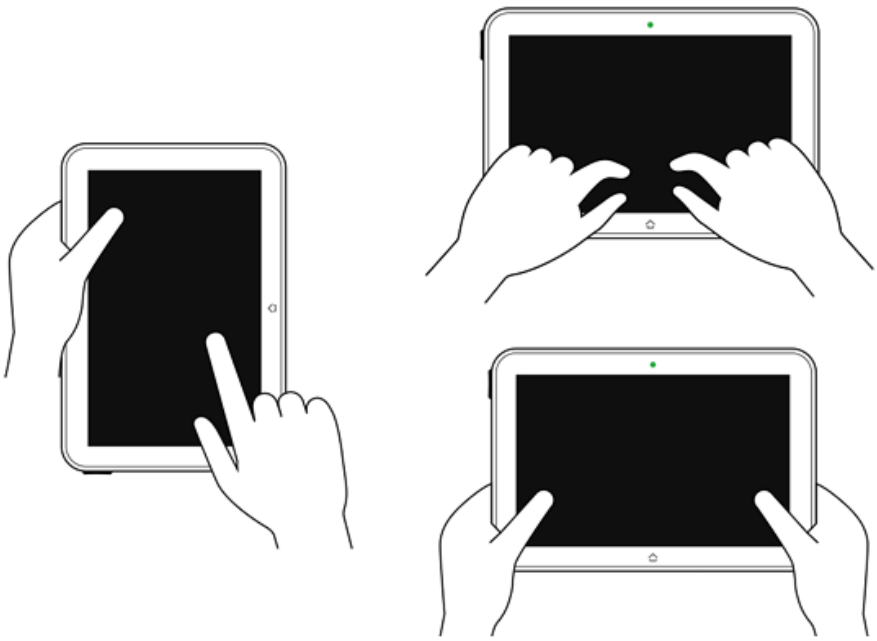

FIGURE 12. Ways of holding a tablet (Wroblewski 2012)

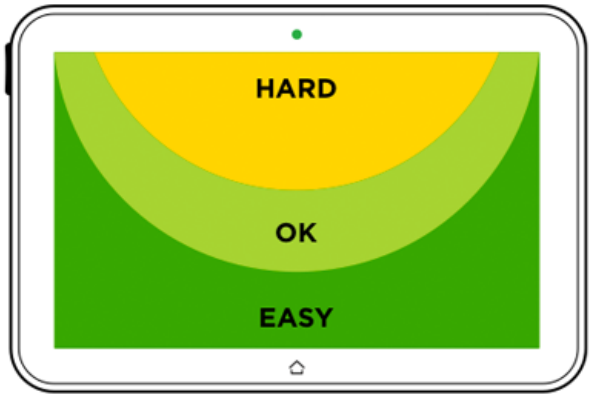

FIGURE 13. Reachability of areas on a tablet (Wroblewski 2012)

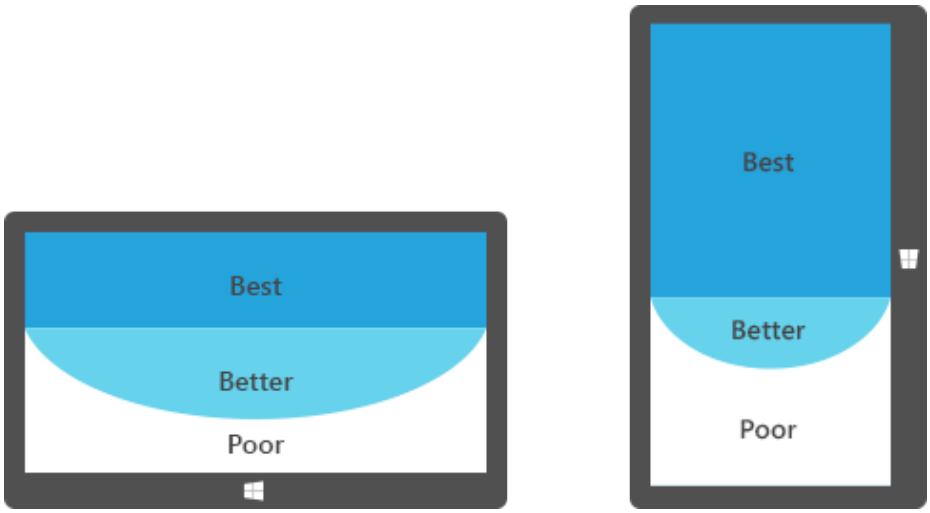

FIGURE 14. Reading areas on a tablet (Microsoft 2015)

Hybrid devices that feature touch, mouse, and keyboard input (figure 15) are getting increasingly common as well. Wroblewski explains the trend is that every screen is slowly but surely becoming a touchscreen: regarding to his presentation at Convey UX 2013 conference, touch is making its way on laptops, and in the future it will be hard to buy a Windows laptop that does not have a touchscreen. (Wroblewski 2013a.) Google has also released Chromebooks that support touch (Google 2014).

A study conducted by Intel (according to Baxter-Reynolds 2012) found out that when given the free choice, most users preferred touch over other input types: 77% of interactions on hybrid devices were made with the touchscreen, 12% with the mouse,

3% with the trackpad and 8% with the keyboard. They also reported that the touchscreen felt more intimate and direct. To avoid the fatigue that comes from holding arms up in the air, often casually called as “gorilla-arm effect”, users rest their arms low and rely on the sides of the screen for touch input (Wroblewski 2013c; Hincapié-Ramos et al. 2014).

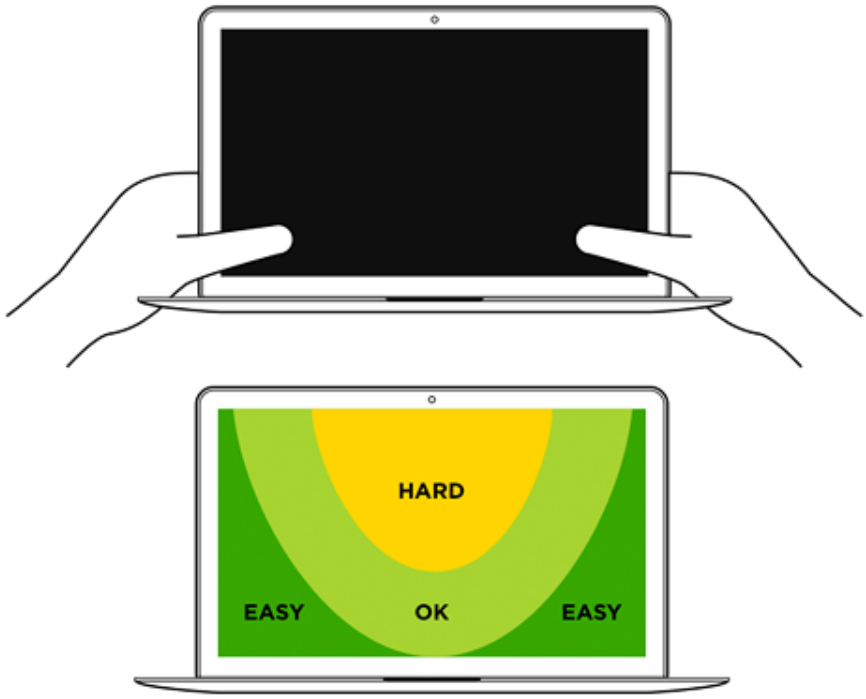

FIGURE 15. Reachability of areas on a touch-enabled laptop (Wroblewski 2012)

5.6 One-handed usage

According to the observations made in the research of Hoober (2013), people often hold their smartphones in one hand. In addition, Clark (2012, 292) explains that right-handed people sometimes use their phones with their left hand, and left-handed sometimes swap their phone to their right hand. Therefore, it is not possible to divide the users into two groups based on their handedness. He advises the best way to go with the design is therefore to create interfaces that are neutral to hand. For example, buttons can spread across the entire width of the screen.

5.7 Social influences and limited attention

Since mobile devices can be accessed everywhere and at any time, they are often used in short bursts. People can use their devices while doing other things, to conduct tasks, or to get information quickly. Even if the user is focused solely on a single task, notification from another application might appear to distract them from what they were doing. Many mobile users are also engaging in conversations or other social situations: they may pass around the device to show people something on the screen, they may need to suddenly turn off the sound, or they may turn it up to let others hear something. Designs should therefore be made for distracted users, and the task sequences should be self-explanatory, quick, and reentrant. (Tidwell 2010.)

5.8 Visibility, discoverability and memorability of actions

In the current touch interfaces, gestures other than tapping buttons and manipulating sliders are usually not visibly indicated, and therefore users may have trouble knowing which gestures are available and how should they be performed. When gestures are related to visual objects, users can try to manipulate them to see if there are actions available. But the more abstract and complex the gesture is, the harder it becomes to remember. In addition, abstract gestures can be complex: they can involve one or multiple fingers, single or multiple taps, and movements in various ways such as up, down, left, right or circular (Norman & Wadia 2013). In addition, performing the gesture may trigger different actions depending on its location on the screen.

5.9 Accidents with no easy, immediate recovery option

Especially when using the interface for the first time, users may accidentally perform touch gestures. In these occasions, an option for undoing things would help the user to go back, especially if the gesture has taken the user to a new location. For example, if the user unintentionally presses a wrong button in an application, it may be hard to know why the resulting action took place. Touch interfaces do not generally have possibilities for undoing these actions, yet some mobile devices accommodate a back button. (Norman & Wadia 2013).

5.10 Lack of haptic feedback

Although being directly manipulated with fingers, the elements on a touchscreen do not give the same tactical response such as physical buttons or keyboards. This can be quickly noticed when typing text on touchscreens, where it is easier to make typing errors than using physical buttons. The first generation haptic feedback has already been widely available on mobile devices in form of vibratory motor, but the technique is limited to a small number of sensations and that the entire device vibrates as a whole (Alur, Jumde & Shrivastav 2014, 6039). Commonly, touchscreen users have to rely on visual and audio feedback (Kuutti 2003, 32). Due to this, touchscreens are hard to use for visually impaired or blind people. However, commercial solutions to these problems may be available in the future, since several companies are currently working on developing haptic technology (Alur et al. 2014).

5.11 Guiding users to use touch interfaces

When the first touch interfaces entered the market, usability was an important aspect defining their success. How has the usage of touch interfaces been guided to users?

The first iPhone was a new kind of device to the users. By using metaphors, it succeeded in linking the future with the past, and made people feel at ease with the new device. The operating system of the first iPhone had a various metaphors for helping users to directly interact with the screen, such as using sliders for activating settings. (Judah 2013; Worstall 2013.)

Using elements that have existed before can be useful, even though some of them have been criticized based on that the younger generations are not necessarily familiar to the older items (Worstall 2013). When the technology has been matured and largely adopted by users, the visuals have turned simpler and usage of metaphors has become more subtle.

Consequently, people have learned how to use their mobile devices, but generally they have not been thoroughly guided to use all of the touchscreen functionality. Especially usage of gestures has been poorly guided and therefore the users have often learned to

use them by performing the gesture accidentally, from other users, or from web sources (Spool 2013). Abstract gestures particularly are hard to find without visual cues or explicit guidance (Clark 2102, 327). According to Clark (2012, 327–333), a better approach would be to guide the usage of unfamiliar interfaces gradually and contextually. He suggests the following ways that have been used on mobile games: *Coaching*: indicating that there is a function available, for example by showing animation cues or an overlay that disappears after the user has successfully performed the action. *Leveling up*: not teaching all features at once, but building on the basics and then revealing more advanced levels the user has to accomplish to proceed further. *Power-ups*: When the user has learned the basic features, giving hints about the available shortcuts.

5.12 Lack of standards

Due to various operating systems and their diverse physical properties, mobile users must always adapt to new forms of interaction as they switch between different devices (Bertini et al. 2009). Furthermore, competing companies have developed their own language of interaction and gestures (Norman & Wadia 2013). These various options pose challenges for the user in learning and remembering the required actions. Nielsen and Norman (2010) conclude that usability guidelines based upon solid principles of interaction design should be developed for touch gestures.

Whereas the problem of competing manufacturers and operating systems is harder to solve, there is a way to avoid problems related to touch gestures, their visibility and memory load: using gestures as accelerators. According to Nielsen (1994, 193), accelerators are user interface elements that allow the user to perform frequent tasks quickly, even though the same tasks can also be performed in a more general and possibly slower way. Clark (2012, 313) recommends the same – when there is another, visible option available, users who have not discovered the gesture can still find the function. One example of using a gesture as accelerator is the default browser in iOS which has a back button, but going back is possible also by swiping over the left edge of the screen.

6 USABILITY EVALUATION IN MOBILE ENVIRONMENT

The ISO 9241 standard defines usability as ”the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction, in a specified context of use” (ISO 9241, according to Inostroz et al. 2012). Nielsen (1994, 26) concludes that usability is traditionally associated with the attributes such as learnability, efficiency, memorability, low error rate and user satisfaction.

Usability is a narrow concern compared to the larger issue of system acceptability (figure 16). Especially in the case of mobile devices, usability is only one part of the broader context that defines the success of a product.

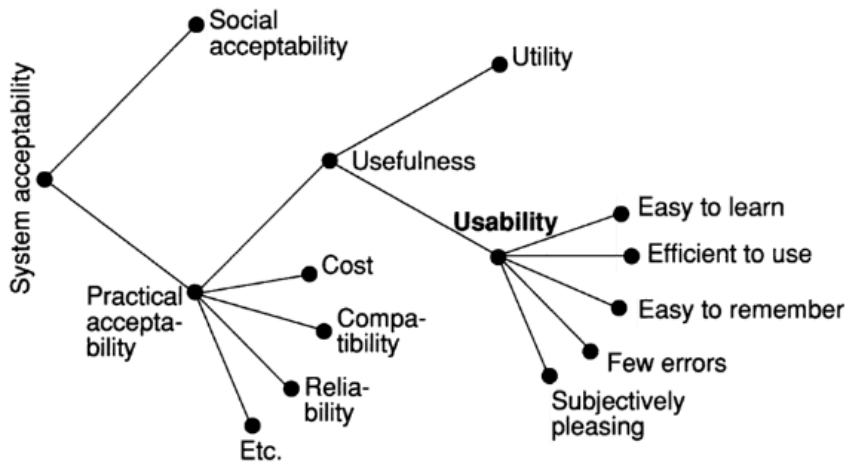

FIGURE 16. A model of the attributes of system acceptability (Nielsen 1994, 25)

Alanne (2002, 15), according to the writings of Nielsen (1993, 25), summarises that usability is a fundamental feature of system acceptability: without being usable the software can not be useful. In addition, usability-related features such as emphasising quick learnability or efficiency of the interface can be used as a distinguishing feature in the mobile market (Inostroz et al. 2012; Roppola 2014).

6.1 Heuristic evaluation

The primary objective of heuristic evaluation is to identify usability problems by inspecting the interface. Pioneered by Jakob Nielsen, the process is about evaluating the effectiveness of the interface based on industry standards or principles. Heuristic evaluation has been widely applied and investigated and various heuristics have been developed to suit for different purposes. (Bertini et al. 2009, 1.) Compared to full user studies, heuristic evaluation can be highly cost-effective, allowing a large amount of usability flaws to be detected with limited resource investment (Lowdermilk 2013). It can also be effectively conducted by non-usability experts (Bertini et al. 2009).

However, it is worth noticing that expert-based techniques have been criticized for finding proportionately fewer problems than other evaluation methods, and more cosmetic problems (Campbell, Fiegel & Karat 1992, according to Bertini et al. 2009). Like other inspection methods, heuristic evaluation is vulnerable to expert biases as well (Cockton, Lavery & Woolrych 2003, according to Bertini et al. 2009). Furthermore, heuristic evaluation should not be used as the only evaluating method. Combining heuristic evaluation with user testing is recommendable as the two methods tend to complete each other in finding different types of usability problems. (Nielsen 2008.)

According to Nielsen (1995), single evaluators tend to find 35% of the usability problems, but since the evaluators tend to find different problems, 3–5 is the amount of evaluators he recommends in most cases. However, it is not a problem in this case, since I am performing the evaluation for devices and operating systems that are already commonly used, and my findings do not directly affect to their development.

Inostroz et al. (2012) argue that the traditional expert-based methods for usability measuring such as using Nielsen's heuristics do not fit the nature of mobile devices in every aspect: they do not consider the particularities related to touchscreens. In addition, their ability to capture the multiple contextual factors that affect interactions in real settings has been questioned (Bertini, Gabrielli & Kimani 2006).

To meet these challenges, Inostroz et al. (2012) conducted a study where they developed a set of eleven specific usability heuristics based on Nielsen's heuristics, but modified for touchscreen-based mobile devices. In a preliminary validation the authors

found out their heuristics to be more effective than Nielsen's heuristics, though they state more experiments are still necessary. Compared to Nielsen's heuristics, these heuristics take mobile features carefully into account, even though the names of the heuristics remained mostly similar. The biggest refinement was introducing the eleventh heuristic for ergonomics. These heuristics are used in this thesis for measuring usability of smartphones and their operating systems.

In heuristic evaluation, severity of violations is usually evaluated based on how important they are to correct. In my evaluation, the devices already being in the market, I will limit the focus on briefly evaluating how severe the problems are from usability perspective, and do not suggest whether these problems should be corrected or not.

7 USABILITY ANALYSIS OF FOUR SMARTPHONES AND THEIR OPERATING SYSTEMS

According to a TNS Gallup Finland report provided by P.C.E. Helsinki, the most popular operating systems in Finland in August 2014 were Android with 38% market share, Windows Phone with 32%, and iOS with 14%. Sailfish was holding 1% of the market share (eMarketer 2014). The analysed devices in this thesis therefore include the most popular smartphone operating systems in Finland.

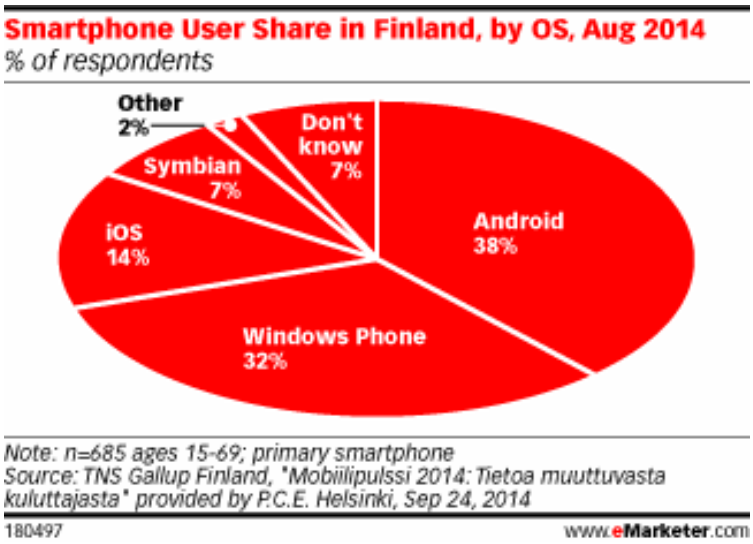

FIGURE 17. Smartphone user share in Finland by OS in August 2014 (eMarketer 2014)

The goal of the analysis was to provide an overview of the devices and operating systems in the market and to explore how have they utilized the touch element, how have they solved touch-related interaction challenges, and what usability problems there currently are. Virtual keyboards and notifications are excluded from the evaluation to limit the scope of the thesis.

7.1 Three levels of interaction

Alshehri and Freeman (2014) argue that usability is typically only concerned with the device's screen interface rather than the device as a whole. Instead, all interaction layers of mobile devices: hardware, operating system and application, should be taken into

account (figure 18). For example, in Android hardware is Samsung, operating system is Android, and many of applications are developed by third parties, though there are system applications as well. In the following evaluation, I will cover all these interaction levels.

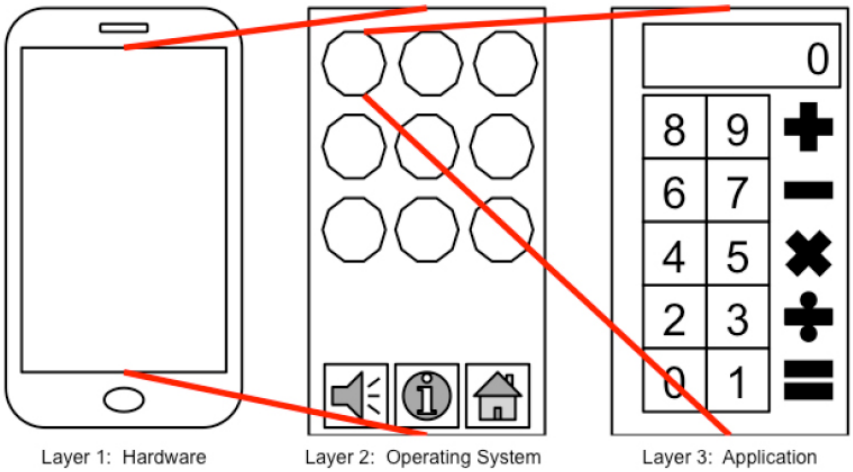

FIGURE 18. Device interaction layers according to Alshehri and Freeman (2014)

Alshehri and Freeman (2014) included web in the category of third layer, but I would consider web as fourth layer. Web is operated in a browser application, but it still has an interface with various interaction options.

7.2 Analysed mobile devices and their operating systems

7.2.1 iPhone 5 (iOS 8.2)

In iPhone 5, the only physical button in the front screen is the home button. On the left side it accommodates two buttons and one switch, and one button in the top, which is for lock screen. What is unique to the operating system is that the main view accommodates various shortcuts which are available through swiping to different directions, and by using long press and double-press on the home button. This results in minimalistic design, but also in low visibility of certain functionality.

7.2.2 Samsung Galaxy Mega 6.3 GT-19205 (Android 4.4.2)

Compared to the other evaluated operating systems, Android provides the highest amount of options for customization. The device can also be categorised as phablet due to its large size. As usually in desktop context where right-click opens a contextual menu, long press on an element on Android brings new options that appear in a pop-up menu. The main navigating buttons on the lower end of the device afford opening a new menu and help, going home and going back. Back button leads the view towards the home screen, and does not afford going back after reaching it.

7.2.3 Nokia Lumia 920 (Windows Phone 8.0)

The device accommodates three buttons on the lower end: back, home and search. The back button, contrarily to Android, takes the view back in history. The back button also affords going back inside a browser application. Search button on the lower left corner is a shortcut for conducting web search.

7.2.4 Jolla (Sailfish 1.0.8.19)

As Alanne (2002) summarises, goal of the design is not always to create as easy-to-use interface as possible: for example efficiency can be a more important factor. This shows up in the Jolla smartphone and Sailfish operating system. It is optimised for one-handed usage and also works well on both left and right hand. Main functions, such as going back to home screen and closing the current application, are based on swipes that are equally easy to conduct from both left and right sides of the screen. Market differentiation and practical constraints have been the reasons behind the interface design decisions (Roppola 2014).

7.3 Heuristics for touchscreen mobile devices

Along time, different heuristics have been modified and adapted for different sort of products, for web, and for specialised user groups (Barnum 2010, 63). Heuristics have also been developed for touchscreen mobile devices, and I will use heuristics developed by Inostroza et al. (2012) for my evaluation. These heuristics are based on Nielsen's ten heuristics, but they are adapted for evaluating touchscreen-based mobile devices and also take ergonomics into account. Although the names of most heuristics are similar to Nielsen's, their definitions are often substantially different (Inostroza et al. 2012, 665).

7.3.1 TMD1 – Visibility of system status

The device should keep the user informed about all the processes and state changes through the use of a specific kind of feedback, in a reasonable time.

Hardware and OS level

None of the smartphones violated this heuristic.

Application level

None of the smartphones violated this heuristic.

7.3.2 TMD2 – Match between system and the real world

The device should speak the users' language with words, phrases and concepts familiar to the user, instead of system-oriented concepts and/or technicalities. The device should follow the real world conventions and physical laws, displaying the information in a logical and natural order.

Hardware and OS level

Android: As providing a lot of options and menus for adjusting detailed settings, Android also presents some concepts that are not familiar to most users.

Sailfish: The violation related to displaying the information in a logical and natural order appears in the submenus. One example of this is the usage of submenus that are located on the upper side of the interface. For example, in the settings for adjusting wireless networks, the option for adding a network is opened by sliding down and the option locating on the upper side, not after the found network list as expected. In these situations, the user often expects to find visible buttons, especially if there is plenty of empty space on the screen.

Application level

No violations in any of the devices.

7.3.3 TMD3 – User control and freedom

The device should allow the user to undo and redo his actions, and it should provide "emergency exits" to leave the unwanted state. These options should be clearly pointed, preferably through a physical button or similar; the user shouldn't be forced to pass through an extended dialogue.

Hardware and OS level

iOS: There is an option for undoing and redoing typing, which is by shaking the device and choosing either one of the options. However, this gesture is not clearly pointed and does not accommodate a physical button.

Android: There are no options for undo or redo. Back button is located in the lower right corner of the screen, but in the default settings it is hardly visible. The back button is not a physical one either.

Windows Phone: There are no options for undo or redo. Back and home buttons work as emergency exits to leave the unwanted state, but the violation is that they are not physical, pressable buttons.

Sailfish: There are no options for undo or redo. There are neither physical nor touch-based buttons for an emergency exit.

Application level

Windows Phone: Back and home buttons, "emergency exits" for leaving the application, are not physical buttons.

Sailfish: Functions for closing the application or going back to home screen, "emergency exits" for leaving the application, are not physical buttons.

7.3.4 TMD4 – Consistency and standards

The device should follow the established conventions, on condition that the user should be able to do things in a familiar, standard and consistent way.

As I am evaluating the interface based on my own knowledge, I made the decisions based on how unfamiliar and unconventional the interface felt to me, as well as pointed out inconsistencies within the interface itself.

Hardware and OS level

iOS: In settings, for example when choosing language and region, "Edit" option in the top right corner is not in a logical place related to what the option does. After the option has been selected, next view poses another violation: arranging languages to preferred order is indicated by icons that, in most cases, are related to opening menus instead of rearranging content.

Android: When choosing the option for home screen mode, going back from the top left corner is not available as usual, but the user must select "Cancel", "Save", or press back

button on the top right corner to exit the view. Inconsistently for the user, in some pages the user must save the choices, but in other pages the choices become available by simply tapping them.

Windows Phone: The permanent search icon at the lower right corner of the screen leads to web search, not to search from the phone, as user might expect.

Sailfish: Among the analysed devices, the user interface of Sailfish is the most unconventional. Most people feel using it for the first time to be far from familiar.

Application level

iOS: Action for "search on this page" does not adhere to the same logic as desktop browsers. The word has to be typed on the top address bar, and then option "On This Page" appears in the end of the list. Writing the word first and choosing the option after that does not feel logical, which is based on my previous experiences.

Android: Usually, opened new tabs are empty. Opening a new tab in Android automatically opens Samsung's website.

Sailfish: On the tab view, the first tab does not open by simply tapping it, but requires tapping the address and pressing a button after that.

7.3.5 TMD5 – Error prevention

The device should have a careful graphic user interface and physical user interface design, in order to prevent errors. The non-available functionalities should be hidden or disabled and the user should be able to get additional information about all available functionality. Users should be warned when errors are likely to occur.

Hardware and OS level

Windows Phone: Physical button on the right side of the device brings up camera functionality. Due to the placement of the button, it can be accidentally pressed, and pressing the button again in this situation does not stop the function but instead takes a photo.

Application level

Sailfish: When reaching for the top left corner while browsing the web on portrait orientation, it is easy to accidentally trigger landscape orientation.

7.3.6 TMD6 – Minimize the user's memory load

The device should minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

Hardware and OS level

iOS: In the main view, many of the options are only available by using gestures, such as swipe from center to down for searching the phone, and not indicated in a visible way. No instructions for use of the interface are available either. Information of where to find all open applications is not visible. Thumbnail view displays the recently used applications.

Android: In the settings menu, some elements show a slider. They also have a sublevel, but it is not indicated in any way. Help for using functions is available by pressing the button on the lower left of the screen, but the button is not visible by default.

Windows Phone: Information of where to find all open applications is not visible.

Sailfish: Main functions are gesture-based, which makes them invisible and user has to remember how are they activated and are they located.

Application level

iOS: Finding a word on a website is not easy since the function is located on the list which appears while typing a web address. Options for adding a website to favorites or requesting desktop site appear only when the bookmark view is slided down, and are therefore hard to find.

7.3.7 TMD7 – Customization and shortcuts

The device should provide basic configuration options and should give expert users access to advanced configuration options. The device should provide shortcuts to the most frequent tasks and should allow their customization and/or definition.

In this heuristic, "basic configuration options" and "advanced configuration options" are not explained in detail. Therefore, in hardware and operating system level I categorized "providing options to change and adjust front screen icons" as the basic configuration options, and "providing ability to choose icons in front screen sliders" as advanced configuration options. In application level, I considered "being able to arrange bookmarks and favorite websites" as basic configuration options and everything else beyond that as advanced configuration options.

Hardware and OS level

iOS: Does not give expert users access to advanced configuration options.

Windows Phone: Does not give expert users access to advanced configuration options.

Sailfish: Does not give expert users access to advanced configuration options.

Application level

iOS: Does not give expert users access to advanced configuration options.

Sailfish: Does not give expert users access to advanced configuration options.

7.3.8 TMD8 – Aesthetic and minimalist design

The device should avoid displaying irrelevant or rarely needed information. Each extra information unit reduces the system performance.

Hardware and OS level

Adroid: When presenting numerous customization options, some of them are likely to be rarely needed.

Application level

Adroid: When presenting numerous customization options, some of them are going to be rarely needed.

7.3.9 TMD9 – Help users recognize, diagnose, and recover from errors

Error messages in the device should be expressed in plain language (no codes), precisely indicating the problem, and constructively suggesting a solution.

Hardware and OS level

No violations in any of the devices.

Application level

No violations in any of the devices.

7.3.10 TMD10 – Help and documentation

The device should provide easy-to-find documentation and help, centered on the user's current task. A list of concrete (and not too large) steps to carry out should be provided.

Hardware and OS level

iOS: Does not guide the usage of operating system at all.

Windows Phone: Provides help in settings, but not located on the current task.

Sailfish: Provides a guide as an application, but not always help related to the user's current task.

7.3.11 TMD11 – Physical interaction and ergonomics

The device should provide physical buttons or similar user interface elements for main functionalities. Elements should be placed in a recognizable position. The device dimensions, shape, and user interface elements in general, should fit the natural posture of the hand.

Hardware and OS level

Windows Phone: Home button is not a physical one. The device shape and especially the back button are difficult in one-handed, right-handed usage. The lower left edge is hard to reach, especially when the corners of the device are relatively sharp.

Sailfish: No physical buttons for the main functionalities. Positioning of the main functions, such as navigating to home screen, is not visually recognisable either.

8 CONCLUSIONS AND DISCUSSION

As the result of the thesis I provided an overview of usability of the current touchscreen mobile devices. Heuristic evaluation was used as a tool to analyse what kind of challenges the current devices pose to the users.

The results indicate that touch-based mobile operating systems have some usability issues. Each operating system has an unique interface which is based on different design decisions and priorities, and the results show heuristic violations have therefore been spread out on various areas.

I evaluated the severity of violations in three levels: mild violations indicated with yellow, medium-level violations indicated with orange, and severe violations indicated with red. However, none of the violations was evaluated as severe.

In conclusion, iOS gained the least amount of violations whereas Sailfish gained the biggest amount of them (table 1). However, the results are suggestive, since they are based on one evaluator, and more evaluators would improve the validity of the results.

TABLE 1. Heuristic evaluation in hardware and OS levels

		Levels of interaction 1 & 2: Hardware & OS level			
	Heuristic for Touchscreen Mobile Devices	iOS	Android	Windows Phone	Sailfish
1	Visibility of system status				
2	Match between system and the real world		1,0		1,0
3	User control and freedom	0,5	1,0	1,0	1,0
4	Consistency and standards	1,0	1,0	0,5	1,0
5	Error prevention			0,5	
6	Minimize the user's memory load	0,5	1,0	0,5	1,0
7	Customization and shortcuts	0,5		0,5	0,5
8	Aesthetic and minimalist design		1,0		
9	Help users recognize, diagnose, and recover from errors				
10	Help and documentation	1,0		1,0	1,0
11	Physical interaction and ergonomics			0,5	1,0
		3,5	5,0	4,5	6,5

In application level (table 2), less violations were found. The results are also highly dependent on the selected application, and I believe different applications could have violations in different areas.

TABLE 2. Heuristic evaluation in application level, evaluating each OS default browser

		Level of interaction 3: Application level			
	Heuristic for Touchscreen Mobile Devices	iOS	Android	Windows Phone	Sailfish
1	Visibility of system status				
2	Match between system and the real world				
3	User control and freedom			0,5	1,0
4	Consistency and standards	1,0			1,0
5	Error prevention			1,0	
6	Minimize the user's memory load	1,0			
7	Customization and shortcuts	0,5			0,5
8	Aesthetic and minimalist design		1,0		
9	Help users recognize, diagnose, and recover from errors				
10	(This heuristic only applies to the system level.)				
11	(This heuristic only applies to the system level.)				
		2,5	1,0	1,5	2,5

Most violations, with amount of 5,5 points in total, happened in area of *4: Consistency and standards*. Obviously, touch interfaces do not have standards yet, and their interfaces are different than desktop interfaces. Second most amount of violations with 5 points was found in area of *3: User control and freedom*, which highly relates to lack of undo options. Thirdly, *6: Minimize the user's memory load*, was rated with 4 points. Most violations in this area were related to low visibility of actions since the actions were based only on invisible gestures.

Overall, the results indicate there is still room for improvements. However, I believe that improving visibility of objects and actions could also result in violations in aesthetic and minimalist design. Using on-the-task help could be a solution for this, since it would lessen violations in the area of minimizing the user's memory load, and provide help and documentation in a way that still enables maintaining aesthetic and minimalist design.

9 REFERENCES

Alanne, M. 2002. Käytettävyyden kehittämisprosessin uudistaminen isolle ohjelmistotalolle. Helsingin kauppakorkeakoulu. Johtamisen laitos. Master's thesis.

Alshehri, F. & Freeman, M. 2014. User Experience of Mobile Devices: A Three Layer Method of Evaluation. 25th Australasian Conference on Information Systems 8th -10th Dec 2014, Auckland, New Zealand.

Alur, A., Jumde, A. & Shrivastav, P. 2014. Haptic Technology: A Comprehensive Review of its Applications and Future Prospects. International Journal of Computer Science and Information Technologies, Vol. 5, 2014.

Arokoski A., Jääskeläinen, J. Kontio M., Köykkä S., Raatikainen S., Tervo, T. & Vierimaa K. 2002. Mobiiliteknologiat. Helsinki: Edita.

Almazán, M. & Sitbon, E. 2014. Smartphones & Mobile Money: The Next Generation of Digital Financial Inclusion. [Discussion paper]. Released 10.7.2014. Read 8.8.2014. http://www.gsma.com/mobilefordevelopment/smartphones-mobile-money-the-next-generation-of-digital-financial-inclusion

Barnum, C. 2010. Usability Testing Essentials. Morgan Kaufmann; Safari Books Online. http://my.safaribooksonline.com/book/software-engineering-and-development/software-testing/9780123750921

Baxter-Reynolds, M. 2012. The Human Touch: Building Ultrabook™ Applications in a Post-PC Age. Released 11.7.2012. Read 2.7.2014. https://software.intel.com/en-us/articles/the-human-touch-building-ultrabook-applications-in-a-post-pc-age/

Bertini, E., Catarci, C., Dix, A., Gabrielli, S., Kimani, S. & Santucci, G. 2009. Appropriating Heuristic Evaluation for Mobile Computing. International Journal of Mobile Human Computer Interaction, 1(1), 20-41, January-March 2009.

Bertini, E., Gabrielli, S. & Kimani, S. 2006. Appropriating and Assessing Heuristics for Mobile Computing. AVI '06, May 23–26, 2006, Venezia, Italy.

Campbell, R., Fiegel, T. & Karat, C.-M. 1992. Comparison of empirical testing and walkthrough methods in user interface evaluation. CHI'92, pages 397–404. ACM Press.

Clark, J. 2012. Designing for touch. The Mobile Book. Freiburg: Smashing Media GmbH.

Clayton, S. 2012. Are We Moving Toward A More Natural Future With Technology? Released 31.3.2012. Read 14.10.2014. http://www.psfk.com/2012/03/natural-future-wtechnology.html

Cockton, G., Lavery, D. & Woolrych, A. 2003. Inspection-based Evaluations. In J.A. Jacko & A. Sears (Eds.), The HCI Handbook, Lawrence Erl. Assoc.

Constine, J. 2013. Facebook Reveals 78% Of US Users Are Mobile As It Starts Sharing User Counts By Country. Released 13.8.2013. Read 4.8.2014. http://techcrunch.com/2013/08/13/facebook-mobile-user-count/

Cooper, A., Cronin, D. & Reimann, R. 2007. About Face 3: The Essentials of Interaction Design. John Wiley & Sons; Safari Books Online. https://www.safaribooksonline.com/library/view/about-face-3/9780470084113/

Dambrāns, K. 2013. Samsung Galaxy Note 3 One-handed mode. [Photo.] Read 17.12.2014. https://www.flickr.com/photos/janitors/10065625935

Danova, T. 2014. The Mobile Revolution Is The Biggest Tech Shift In Years, And Companies Are In A Race To Keep Up. Released 23.1.2014. Read 12.7.2014. http://www.businessinsider.com/mobile-media-consumption-grows-2-2014-1?IR=T

Duce, D., Flood, D. & Harrison, R. 2013. Usability of Mobile Applications: Literature Review and Rationale for A New Usability Model. Journal of Interaction Science 2013.

eMarketer. 2014. Android Leads Finland's Smartphone Market (but Not by Much). Released 21.10.2014. Read 25.2.2015. http://www.emarketer.com/Article.aspx?R=1011346

Evans, B. 2013. Slides: Mobile is eating the world. Released 10.11.2013. Read 7.9.2014. http://qz.com/145704/slides-mobile-is-eating-the-world

Farago, P. 2012. iOS and Android Adoption Explodes Internationally. Released 27.8.2012. Read 25.2.2015. http://www.flurry.com/bid/88867/iOS-and-Android-Adoption-Explodes-Internationally

Fekete, G. 2009. Operating System Interface Design Between 1981-2009. Released 11.3.2009. Read 28.2.2015. http://www.webdesignerdepot.com/2009/03/operating-system-interface-design-between-1981-2009/

Fling, B. 2009. Mobile Design and Development. O'Reilly Media, Inc; Safari Books Online. https://www.safaribooksonline.com/library/view/mobile-design-and/9780596806231/

Fogg, I. 2012. Five years of iPhone disruption. Released 22.7.2012. Read 20.10.2014. https://technology.ihs.com/408607/

Goldman, J. 2010. Apple Sells 1 Million iPads. Released 3.5.2010. Read 5.7.2014. http://www.cnbc.com/id/36911690

Google. The Acer C720P. Read 27.8.2014. http://www.google.com/chrome/devices/acer-c720p-chromebook/

Google Developers. 2015. Use Legible Font Sizes. Updated 8.4.2015. Read 30.4.2015. https://developers.google.com/speed/docs/insights/UseLegibleFontSizes

Hincapié-Ramos, J., Guo, X., Moghadasian, P. & Irani, P. 2014. Consumed Endurance: A Metric to Quantify Arm Fatigue Mid-of Air Interactions. CHI 2014, April 26 - May 01 2014, Toronto, ON, Canada.

Hoober, S. 2013. How Do Users Really Hold Mobile Devices? Released: 18.2.2013. Read 28.8.2014. http://www.uxmatters.com/mt/archives/2013/02/how-do-users-really-hold-mobile-devices.php

Hoober, S. 2014. The Social History of the Smartphone. Released 7.7.2014. Read 3.8.2014. http://www.uxmatters.com/mt/archives/2014/07/the-social-history-of-the-smartphone.php

Huddleston, R. 2012. Android® Fully Loaded. John Wiley & Sons; Safari Books Online. Second edition. https://www.safaribooksonline.com/library/view/android-fully-loaded/9781118173022/

Hurff, S. 2014. How to Design for Thumbs in the Era of Huge Screens. Released 19.9.2014. Read 12.12.2014. http://gizmodo.com/how-to-design-for-thumbs-in-the-era-of-huge-screens-1636955848

iClarified. iOS 6 vs. iOS 7: A Side by Side Comparison. Released 19.9.2013. Read 10.11.2014. http://www.iclarified.com/33970/ios-6-vs-ios-7-a-side-by-side-comparison-image-gallery

Inostroz R., Rusu C., Roncagliolo S., Jiménez C. & Rusu V. 2012. Usability Heuristics for Touchscreen-based Mobile Devices. 2012 Ninth International Conference on Information Technology - New Generations.

iOS Human Interface Guidelines. Designing for iOS. Read 14.9.2014. https://developer.apple.com/library/ios/documentation/UserExperience/Conceptual/MobileHIG/index.html

iOS Human Interface Guidelines. Design Principles. Read 15.9.2014. https://developer.apple.com/library/ios/documentation/UserExperience/Conceptual/MobileHIG/Principles.html

ISO 9241. 1998. Software Ergonomics Requirements for office work with visual display terminal (VDT). ISO 9241, Geneva.

Jacob, R., Girouard, A., Hirshfield L., Horn, M., Shaer, O., Sholovey, E. & Zigelbaum, J. 2008. Reality-Based Interaction: A Framework for Post-WIMP Interfaces. CHI 2008, April 5–10, 2008, Florence, Italy.

Janssen, C. Mobile Device. Read 23.2.2015. http://www.techopedia.com/definition/23586/mobile-device

Judah, S. 2013. What is skeuomorphism? Released 13.6.2013. Read 27.4.2015. http://www.bbc.com/news/magazine-22840833

Kaushik, M. & Jain, R. 2014. Natural User Interfaces: Trend in Virtual Interaction. Released 1.5.2014. Read 7.9.2014. http://arxiv.org/abs/1405.0101

Kharpal, A. 2015. Tablet shipments fall for first time ever. Released 3.2.2015. Read 4.3.2015. http://www.cnbc.com/id/102392029

Kuo-Ying, H. 2009. Challenges in Human-Computer Interaction Design for Mobile Devices. Proceedings of the World Congress on Engineering and Computer Science 2009 Vol I, October 20-22, 2009 (San Francisco, USA)

Kurtenbach, G. 2011. Unnatural user interfaces. Brave NUI World. Morgan Kaufmann; Safari Books Online. https://www.safaribooksonline.com/library/view/brave-nui-world/9780123822314/

Kutliroff, G. & Yanai, Y. 2014. Taking Control of Gesture Interaction. Designing for Emerging Technologies. O'Reilly Media, Inc.; Safari Books Online. https://www.safaribooksonline.com/library/view/designing-for-emerging/9781449370626/

Kuutti, V. 2003. Käytettävyys, suunnittelu ja arviointi. Saarijärvi: Gummerus Kirjapaino Oy.

Lehtimäki, J. 2012. Smashing Android UI. John Wiley & Sons; Safari Books Online. https://www.safaribooksonline.com/library/view/smashing-android-ui/9781118387351/

Lowdermilk, T. 2013. User-Centered Design. O'Reilly Media, Inc.; Safari Books Online. https://www.safaribooksonline.com/library/view/user-centered-design/9781449359812

Merriam-Webster. 2015. Mobile. Read 23.2.2015. http://www.merriam-webster.com/dictionary/mobile

Michaud, T. 2013. Foundations of Web Design: Introduction to HTML & CSS. New Riders; Safari Books Online. http://my.safaribooksonline.com/book/web-development/9780133408270

Microsoft. 2015. Touch interactions for Windows. Read 30.11.2014. https://msdn.microsoft.com/en-us/library/windows/apps/hh465415.aspx

Mottier, C. 2012. "Pull-to-refresh": An Anti UI Pattern on Android. Released 28.3.2012. Read 9.8.2014. http://cyrilmottier.com/2012/03/28/the-pull-to-refresh-an-anti-ui-pattern-on-android/

Müller, H., Gove, J. & Webb, J. 2012. Understanding Tablet Use: A Multi-Method Exploration. MobileHCI'12, September 21–24, 2012 (San Francisco, USA)

Myers, B. 1996. A Brief History of Human Computer Interaction Technology. ACM interactions. Vol. 5, no. 2, March, 1998

Nielsen, J. 1994. Usability Engineering. Morgan Kaufmann; Safari Books Online. http://my.safaribooksonline.com/book/web-development/usability/9780125184069

Nielsen, J. 2008. Characteristics of Usability Problems Found by Heuristic Evaluation. Read 18.5.2015. http://www.useit.com/papers/heuristic/usability_problems.html

Nielsen, J. 2012. Mouse vs. Fingers as Input Device. Released 10.4.2012. Read 9.10.2014. http://www.nngroup.com/articles/mouse-vs-fingers-input-device/

Nielsen, J. & Norman, D. 2010. Gestural Interfaces: A Step Backwards In Usability. Read 13.4.2015. http://www.jnd.org/dn.mss/gestural_interfaces_a_step_backwards_in_usability_6.html

Norman, D. 2011. Gesture Wars. Released 25.8.2011. Read 14.5.2014. http://www.core77.com/posts/20272/gesture-wars-20272

Norman, D. & Wadia, B. 2013. Opportunities and Challenges For Touch and Gesture-Based Systems. Read 26.4.2015. http://www.jnd.org/dn.mss/opportunities_and_ch.html

Oxford Dictionary. Mobile Device. Read 26.2.2015. http://www.oxforddictionaries.com/definition/english/mobile-device?q=mobile+device

Petersen, N. & Stricker, D. 2009. Continuous Natural User Interface: Reducing the Gap Between Real and Digital World. IEEE International Symposium on Mixed and Augmented Reality 2009. Science and Technology Proceedings. 19 -22 October, Orlando, USA.

Ranganathan, K. 2012. Analysing Natural User Interfaces: Literature review. CHI'12, May 5–10, 2012, Austin, Texas, USA.

Raskin, J. 2000. The Humane Interface: New Directions for Designing Interactive Systems. Addison-Wesley Professional; Safari Books Online. http://my.safaribooksonline.com/book/web-design-and-development/0201379376

Rieger, S. 2012. The Future of Mobile. The Mobile Book. Freiburg: Smashing Media GmbH.

Roppola, J. Senior Designer, Jolla. 2014. Interview 22.7.2014. Interviewer Kuisma, S. Transcribed. Tampere.

Rosoff, M. 2015. Here's How Windows Has Changed On PCs And Phones In The Last 30 Years. Released 20.1.2015. Read 28.2.2015. http://uk.businessinsider.com/the-history-of-windows-on-pcs-and-phones-2015-1?op=1?r=US#ixzz3T3wlg5fY

Saffer, D. 2008. Designing Gestural Interfaces. O'Reilly Media, Inc.; Safari Books Online. https://www.safaribooksonline.com/library/view/designing-gestural-interfaces/9780596156756/

Shamonsky, D. 2014. User Experience Design Principles of a Natural User Interface (NUI). Released 24.11.2014. Read 3.12.2014. http://www.ics.com/blog/idea-natural-user-interface-not-naturally-easy-grasp

Shneiderman, B. 1983. Direct Manipulation: A Step Beyond Programming Languages. IEEE Computer, 16(8), 57-69.

Shotts, K. 2014. PhoneGap 3.x Mobile Application Development HOTSHOT. Packt Publishing; Safari Books Online. https://www.safaribooksonline.com/library/view/phonegap-3x-mobile/9781783287925/

Spool, J. 2013. Designing Intuitive Microinteractions. Released 1.8.2013. Read 31.8.2014. http://www.uie.com/articles/intuitive_microinteractions/

StatCounter Global Stats. 2015. Top 8 Mobile Operating Systems from Dec 2008 to Feb 2015. Read 20.4.2015. http://gs.statcounter.com/#mobile_os-ww-monthly-200812-201502

Tidwell, J. 2010. Designing Interfaces. O'Reilly Media, Inc.; Safari Books Online. Second edition. https://www.safaribooksonline.com/library/view/designing-interfaces-2nd/9781449379711/

Tennant, B. 2011. 16 Pixels: For Body Copy. Anything Less Is A Costly Mistake. Released 7.10.2011. Read 30.4.2015. http://www.smashingmagazine.com/2011/10/07/16-pixels-body-copy-anything-less-costly-mistake/

Voorhees, G. 2013. An Event Apart SF 2013 Recap. Released 13.12.2013. Read 8.8.2014. http://www.chapterthree.com/blog/event-apart-sf-2013-recap

Wigdor, D. & Wixon D. 2011. Brave NUI World. Morgan Kaufmann; Safari Books Online. http://my.safaribooksonline.com/book/software-engineering-and-development/9780123822314/chapter-5-contextual-environments/29

Wigdor, D. & Wixon D. 2011. Brave NUI World. Morgan Kaufmann; Safari Books Online. https://www.safaribooksonline.com/library/view/brave-nui-world/9780123822314/

Wiggins, R. 2004. Personal Digital Assistants. J Digit Imaging. 2004 Mar; 17(1): 5–17.

Worstall, T. 2013. Apple's iOS7, Well, It Was Time For Skeuomorphism To Die. Released 19.9.2013. Read 27.4.2015. http://www.forbes.com/sites/timworstall/2013/09/19/apples-ios7-well-it-was-time-for-skeuomorphism-to-die/

Wroblewski, L. 2010. Touch Gesture Reference Guide. Released 20.8.2010. Read 3.4.2014. http://www.lukew.com/ff/entry.asp?1841

Wroblewski, L. 2011. Mobile First. A Book Apart; Safari Books Online. https://www.safaribooksonline.com/library/view/mobile-first/9780133052893/

Wroblewski, L. 2012. Responsive Navigation: Optimizing for Touch Across Devices. Released 2.11.2012. Read 3.3.2014. http://www.lukew.com/ff/entry.asp?1649

Wroblewski, L. 2013a. Designing for Touch. ConveyUX 2013. [Video]. Released 25.6.2013. Watched 5.7.2014. https://www.youtube.com/watch?v=xwQZiqTlVEA

Wroblewski, L. 2013b. How to Adjust Controls for Touch. [Video]. Released 18.10.2013. Watched 4.7.2014. https://www.youtube.com/watch?v=iflJo0TJD9E&list=PLg-UKERBljNy2Yem3RJkYL1V70dpzkysC&index=3

Wroblewski, L. 2013c. New Layouts for the Multi-Device Web. Released 13.5.2013. Read 4.5.2014. http://www.lukew.com/ff/entry.asp?1721

Wroblewski, L. 2013d. The Mobile Moment. Released 29.12.2013. Read 3.8.2014. http://www.lukew.com/ff/entry.asp?1841