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To Touch or not to Touch

– A comparison between traditional and touchscreen interface within personal computers

Authors: Borislav Lazarov and Rafael Zerega

Tutor: Mauri Kaipainen

Abstract

Touchscreen technology is gradually becoming more popular and massive in our present society to the point where it is hard to find a person that has never used this interface system. Handheld devices such as mobile phones and tablets are predominantly based on touchscreens as the main way to interact with them. Nevertheless, that is not the case when it comes to personal computers either desktop machines or laptops which are still chiefly based on traditional keyboard and mouse as their main input system.

In this study we explore the potential that touchscreen based interface can offer for personal computers carrying through an observational experiment with six participants that were asked to perform a list of tasks using both traditional keyboard-mouse interface and touchscreen interface. The measurements during the observation concerned time and error rate for every task. Each participant was interviewed right after the completion of the observational phase in order to get a qualitative insight on their views and perceptions regarding both interfaces. The data collected was analyzed based on some existing models within touchscreen interface and human-computer interaction that have been elaborated in previews research. The final results led to the conclusion, that touchscreen-based interface proved to be slower and have higher error rate than traditional interface in a big number of the tasks performed by the participants. Similarly, the general perception of the people towards having touchscreen on a personal computer still seems a bit doubtful, although they do see some concrete positive aspects about this interface. Nevertheless, touchscreen outperformed traditional interface in some particular tasks. This implies that touchscreen interface has a clear potential for personal computers that would let users utilize these machines in a much broader and more interactive way than people do it today with the traditional keyboard-mouse interface.

Keywords: Touchscreen, User Interface, Human-Computer Interaction, Personal Computer, Usability, Fitts' Law.

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1. INTRODUCTION

Ever since the beginning of the personal computing era, roughly three decades ago, the main input system that users had for interacting with these machines was a physical keyboard. Shortly after, the introduction of the mouse as a pointer device revolutionized personal computers making them easier and faster to use. During the last decade a new interface system based on touchscreen has made its debut especially among mobile phones and tablet devices. But even though this interface mode has become widely accepted and massified among these handheld devices, the same cannot be said in relation to personal computers where the main interacting system is still chiefly based on the use of a physical keyboard and mouse.

In order to make personal computers a truly multipurpose device capable of running a wide variety of applications these machines must have a flexible interface system that allows the users to interact with them in ways that go way beyond the possibilities that a physical keyboard and a mouse can offer. This essay explores how suitable can touchscreen technology be for the current generation of personal computers and operative systems existing today and tries to elucidate some of the improvements that must be done in order to make this interface system effective and simple to use for this kind of machines.

1.1 Definitions

1.1.1 Personal computer

Due to the lack of a unique definition of what a personal computer or also called PC actually implies it is necessary to give a clear definition of what sort of devices will fall into this category. In this study, a personal computer will be any computerized machine that is not handheld. By handheld device it is understood those that are primarily operated while holding them in the hand suspended in the air, such as mobile phones and tablet computers. Consistently with this definition, the concept of personal computer will therefore exclude any of these sorts of handheld devices and will only consider those computers that are mostly operated while being placed lying over a flat surface such as a table or other suitable place. Having this concept into consideration, the machines to be regarded as personal computers will be desktop computers, both those that have the main computer enclosed in a metal case separate from the monitor as well as the so called all-in-one desktop computers, where the computer and the monitor are merged in one single unit. Laptop computers will also be considered to be a personal computer since in most cases they must be placed over a flat surface while being operated. In this essay the terms personal computer and PC will be used indistinctively.

1.1.2 Touchscreen technology

A touchscreen is an interface system that consists of an electronic display that besides showing images can also sense when an object is touching its surface so that users can directly interact with any element showed on the screen by simply touching it with the fingers or other devices, like for instance, a pen. Touchscreen monitors have therefore the capability of being both an output and input interface system. Output in that the monitor shows information in the screen that the user can see and input in that the user can control the objects shown on screen by directly touching them and performing different gestures with the hands so that the computer can understand them as a specific command.

1.1.2.1 Types of touchscreen technologies

Saffer (2009:15) explains that there are several technologies used for letting the computer know when and where in the screen a touch input has taken place. Some of these technologies are:

- **Resistive:** This method consists in using two layers on the screen surface. When the users touch the screen they bring together the two layers, which makes an electrical current to flow between the two layers and thus the computer detects that as a touch input event. This method requires that the user applies pressure over the screen to make an input and does not work properly with multi-touch interface (when the user can make more than one touch input on the screen simultaneously).

- **Surface wave:** This technology uses ultrasonic waves that flow all over the screen surface. When the users touch the screen a portion of these waves is absorbed by the finger and that is the indication for the computer that a touch input has been made.

- **Capacitative:** This type of touchscreen uses a surface that is coated with a material that stores an electrical charge. When the users touch the screen some of that electrical charge is absorbed by their hands that decrease the capacitative layer on precisely that area of the screen, which in turn is understood by the computer as a touch input event.

- **Infrared beams:** This technology is the most used one among touchscreen personal computers due to the fact that it works remarkably well for larger screens (20 inches and more). The infrared beams cross the entire screen surface creating a sort of grid. When the user touches the screen with the finger it disrupts the infrared beams. This disruption gives the location of the touch event thanks to the virtual grid created by the infrared beams.

1.1.2.2 Selection strategies for touchscreen interface

Several different selection strategies have been designed in order to offer an input system that is suitable for touchscreen interface. Sears (1989: 3) describes three main selection strategies: land-on, first-contact and take-off.

- **Land-on strategy:** this strategy takes into account the position of the initial touch for making the selection. If the initial touch happens to be done in a selectable area then a selection of that object will be made, otherwise no selection will take place.

- **First-contact:** with this strategy the users can place their fingers anywhere on the screen and then drag the finger over its surface. No selection will be made until a selectable area is reached in which case the selection will instantly take place.

- **Take-off:** Just like first-contact strategy, the take-off strategy allows the users to place the finger on the screen and drag it over its surface. The difference is that with this strategy the selection will not be made until a selectable area is reached and the users lift the finger from the screen to make the selection. This strategy is particularly useful when the user wants to explore the objects on screen by touching them without necessarily selecting them.

There are other selection strategies besides the ones mentioned above, some of them requiring a second simultaneous touch on screen so that the selection will take place. Different types of tasks can require different selection strategies, for instance, if the user wants to explore the tool bar of a certain program then the take-off strategy suits this purpose remarkably well as it lets the user drag the cursor over the different tools getting a description of each one of them without actually selecting them. For selecting objects that will be then dragged to another position the first-contact strategy is a good alternative because it allows the users to place their fingers with more freedom over the screen: if the users fail placing the finger exactly over the target they can just drag the finger until it reaches it and the selection will be made instantly, without having to lift the finger and try tapping the target again.

1.2 Evolution of touchscreen technology

The recent massification that touchscreen technology has had especially among mobile phones and other electronic devices might suggest that this is a recent technological innovation, nevertheless the fact is that touchscreen monitors were first introduced roughly forty years ago. As it usually happens in high technology development, the first touchscreen-based prototypes were the result of academic work combined with private research laboratories in the late sixties and beginning of the seventies. In 1977 the first truly touchscreen interface system called AccuTouch was developed. This prototype was the first touchscreen computer where the user could make an input by simply touching on the screen using one finger, although this system could not deal with multiple input touch points simultaneously (also called multi-touch interface). Later on, in 1978, and as part of a project called PLATO (programmed logic for automated teaching operations), an early model of a computer equipped with touchscreen monitors was used in the form of a computer terminal used for teaching purposes (Andersson, 2009: 7). During the eighties, some touchscreen monitors started to be introduced, though in a marginal level, in some automatized kiosks and other points of sale as well as in bank ATMs or even in some information offices. Yet this interface system was still completely absent among personal computers and therefore unavailable for most of the general public. In 1983 Hewlett-Packard introduced the HP 150, which could be considered the first personal computer with touchscreen interface to be massively produced and commercialized to the general public. It was not until the 1990s that the first mobile phones and other handheld devices such as personal digital assistant (PDA) started to bring touchscreen technology closer to the common people. In 1994 a joint venture between IBM and Bell South resulted in the production of a mobile phone with touchscreen interface called Simon. Apple computers released in 1993 a PDA called Newton that also had a touchscreen interface that the user could interact with using a pen specifically designed for that purpose. During the second half of the 2000s a series of mobile phones, portable music players, tablet computers and other sort of handheld devices started to massively incorporate touchscreen-based interfaces. Many high technology manufacturers such as Apple, Sony Ericsson, Nokia, Samsung, LG, to mention just a few, have started to make extensive use of this interface system in many of their products. During the last few years and regarding personal computers, some manufacturers such as Sony, Acer and Hewlett-Packard have introduced several models with touchscreen capability. The HP TouchSmart, for instance, was introduced in 2007 and it is a series of models sold in different form factors, such as laptops and all-in-one desktop computers. Nevertheless, the percentage of personal computers equipped with touchscreen interface is still rather low (see section 1.3 to find more details regarding market share of touchscreen personal computer).

1.3 An estimate market share for touchscreen personal computers

An important part of the background is to present some information about how much the touchscreen technology is available for the PC market. Since this is not an economical essay, the estimation of the amount of touchscreen personal computer models in the market is a rough estimate regarding the number of touchscreen models offered in the PC market. The way chosen for that estimation is to analyze some of the major international personal computer producers. Information about eight computer brands HP, Acer, Apple, Lenovo, Asus, Sony, DELL and Toshiba has been collected through revising their official websites (see reference list for the links revised) and looking at the product lines presented there. These particular eight brands were chosen because all of them were in the top 10 list of best computer brands in the website www.the-top-tens.com, which is a site where users can rate and share opinions about different services, companies and brands within the technological industry.

The personal computers products included in the estimation process were desktop computers (including all-in-one desktops, case desktop PCs with separate monitor and mini PCs) and laptops (including notebooks, netbooks and other laptops). The rough estimation includes counting all types of desktops and laptops models that are presented in the official webpages of these eight brands and then calculating in percentages how many touchscreen capable models there are among the total amount of models in the two mentioned categories.

The following is the estimation in percentage of touchscreen personal computers:

- Around 37% is the amount of touchscreen desktop PCs, from the total amount of desktop computers offered by these eight major computer brands.

- Around 3,5% is the amount of touchscreen laptop computers, from the total amount of laptops offered by these eight major computer brands.

These results can be interpreted as that making personal computers with touchscreen technology is still not widely spread among brands. Most of these eight brands have one, at most two touchscreen laptop models. In the case of desktop computers, the situation is slightly different. The number of touch models in this category is bigger, but still somewhat limited. For example, Apple does not produce a single touchscreen model neither in laptops nor in desktop PCs. On the other hand, Asus, Toshiba and Sony offer a rather wide amount of touchscreen desktop PCs. The rest of the brands offer some models of touchscreen PCs, but in a relatively low percentage in comparison with traditional PCs (without touchscreen interface).

1.4 Problem

Why is touchscreen technology still not widely used among personal computers?
To simplify this general problem the following two sub questions have been formulated:

- What is the main difference between using traditional interface (mouse and keyboard) and touchscreen interface in terms of time and error rate?

- What problems do users experience with touchscreen technology within personal computers?

1.5 Purpose

The purpose with this essay is to give a better insight for developers and manufacturers regarding some of the main aspects that need to be improved in order to make touchscreen interface a massive and effective interacting system within personal computers.

1.6 Restrictions

In this study the focus lies on the usage of touchscreen technology within personal computers, where handheld devices such as tablets and smartphones are excluded. As already mentioned in previous sections, the reason for that is, that the handheld devices, despite being similar in many ways, are not regarded in this essay as being the same kind of device as a personal computer. Furthermore the essay's focus lies only in technical aspects of the problem and not in some other aspects that could give an answer to the formulated problem, such as economical topics.

The experiment performed consisting in observing users execute some basic actions and tasks were limited to the usage of a personal computer running Windows 7 operative system only. No other operative systems were analyzed in this study. The equipment used for the experiment was a Hewlett-Packard TouchSmart 610 with touchscreen capability and therefore the analysis of the data will be concerning this model only.

2. KEY CONCEPTS AND PREVIOUS RESEARCH WITHIN TOUCHSCREEN TECHNOLOGY

In this section some key concepts and previous research regarding touchscreen technology are going to be presented to give a better understanding of the main experiment described in the following sections.

2.1 Human-computer Interaction (HCI)

The general branch from which the touchscreen technology originates is human-computer interaction (HCI). Fabio Scali (2010) describes the HCI as the discipline which observes and develops the interaction between a human and a computer system. This involves that the human is placed in the center of this interaction while both, the interactive systems and artifacts are created around and with focus on that center. Scali also mentions that HCI is a multidisciplinary field of study, which means that there are a lot of different sciences involved in the development of it. Paul Dourish (1999) see the historical development of HCI as an attempt to capitalize on the full range of human skills and abilities. He means not only skills acquired by training, but rather natural skills and abilities, such as picking objects, pointing with fingers etc.. Furthermore Dourish explains that the development of HCI followed a trend in the middle of the 1990s called tangible computing. One of the ideas behind this concept is that rather than basing the interaction with computers through physical objects only, such as keyboards, mice and displays, we should also explore our natural skills and how we can use them to easily and intuitively interact with a computer. It is at this point where the enormous potential of touchscreen-based interface becomes clear and one can see the close connection between tangible computing and touchscreen technology. One interesting conclusion that Dourish presents is that the future of HCI lies in the interface becoming more available for wider range of engagements and interactions.

Since, as already mentioned, there are different approaches to HCI, in this essay the touchscreen technology is analyzed from two different perspectives: physical-related issues (the physical interaction between the human and the PC in form of hands usage, gesture usage, angle of the monitor etc.) and software related issues (such as the size of the objects shown on screen, precision level of the cursor, gesture recognition, etc).

2.2 Body usage - touchscreen surface and ergonomic issues

The ideas of Dourish on tangible computing about using natural and physical skills of the human body in HCI have been further developed. In a similar line of thoughts, Klemmer, Harmann and Takayama (2006) emphasize on the improvement that a more intensive usage of our bodies could bring for a more effective HCI. They discuss some practical usage of hands and gestures. When it comes to the hands they argue that more active touch interfaces (when one manipulates the objects by touching them) are better than traditional physical manipulation via keyboard and mouse. Another of their suggestions is a bi-manual touchscreen interface with input to computer systems, which could speed up task performance. This bi-manual usage can be in form of simultaneous actions with both hands or maximizing efficiency by distributing actions between hands. Regarding gesturing (see section 2.4 for more details on gestures), these three authors think that keyboards constrain the gestural abilities and thus hinder the user's thinking and communication with the computer. Brolin (2006) also says that gestures are an important element of the body communication, which can also be quite useful for interacting with a computer. He also mentions several important aspects such as that there is a certain difference between gestures and just a random movement of the fingers while touching the screen. This author also mentions that giving the chance to the users to create and personalize their own gestures could make the interaction between human and computer much more effective and natural.

Dan Saffer (2009) discusses the connection between the human gestures and the sensor coverage area of an interactive computer system. His main point is that the larger this area is the broader is also the gesture (which means the size of the gesture and the amount of possible gestures). For touchscreens the sensor area is limited to the surface size of the screen, but the type of sensors can vary, for example, pressure, light, sound, motion sensors, etc. Saffer underlines the importance of calibrating the sensitivity of the screen no matter what type of touchscreen technology is used, because too sensitive sensors will cause a high rate of unintended touch, while slow sensors could make the system to seem not responsive enough. As already mentioned the size of the screen is also important according to him, because it determines what kind of gestures, broad or small, one hand or two hands, are appropriate and possible to be done. This author gives also a list of topics that gestural interfaces (such as touchscreen) are good for:

- **More natural interactions** – humans are physical creatures and likes direct interaction with objects. The interaction between physical gestures and digital objects feels more natural.

- **Less cumbersome or visible hardware** – the touchscreen allows users to perform actions without the need of intermediary hardware such as keyboard and a mouse, which allow putting the touchscreen interface on places where the traditional systems would be impractical.

- **More flexibility –** a touchscreen allows for many different configurations as opposed to fixed physical buttons. The amount of natural gestures has virtually no limits, as long as they take place in the sensors detecting area.

- **More nuance –** gestures systems can deliver a wealth of meaning in addition to controlling a tool, while traditional input devices are not as able to convey as much subtlety as the human body.

- **More fun** – gestural systems encourage play and exploration of a system by providing a more hands-on experience. It feels more fun to interact with objects directly with your hands.

Except opportunities that touchscreen technology provides for the users in terms of hand usage and gesturing, there are also some complications and problems most of which are ergonomic related issues. Gwanseob Shin and Xinhui Zhu (2011) have compared traditional interface (physical mouse-keyboard set up) and touchscreen interface (touchscreen desktop PC) to find out potential ergonomic concerns that the usage of touchscreen interface within PCs could cause. They have reached the following conclusion: "It was concluded that the use of a touchscreen in desktop PC setting could generate greater biomechanical stress and discomfort than a traditional setting, and it might be attributable to greater or more frequent arm and hand movement in floating arm postures."(p. 949). Both the display tapping and the usage of on-screen virtual keyboard were found problematic. Furthermore the participants of their study have preferred to place the touchscreens closer and lower to their bodies with more tilt of the screen, while using that interface. Two decades earlier, Andrew Seers (1991) experimented with users on different touchscreen monitor angles to find out an angle that generates less fatigue while typing with virtual keyboard. He tested 3 angles $30^{o,}$ 45^o and 75^o from horizontal. The results showed that the users found the 30^o angle to be the best of the three angles in terms of less fatigue and dealing with extended use. Sears concludes that the 30^o angle is good for reducing fatigue, but further testing is required to determine the optimal angle for touchscreen typing. Namahn (2000), who also discusses ergonomic issues, gives the angle of 30^o for touchscreen monitor to be best for precision and comfort, while $22{,}5^o$ has least fatigue. He also points out that the touchscreen interfaces inflict some limitations to the users' position such as: the user must sit/stand within arm's reach of the display and the fact that users made less errors while sitting directly in front of the target to be selected.

Benko , Wilson and Baudisch (2006) wrote about occluding problems caused by, the user's fingertips, hands and arms. The fingertips could cover smaller objects causing the user to touch on wrong area, while the hand and the arm blocking the general view forced the user to either look under hand or over hand, depending also on the angle of the screen.

2.3 Fitts' Law and its relevance within HCI and touchscreen interface

The American psychologist Paul Fitts at the Ohio State University proposed in 1954 a model describing human movement in terms of speed and precision when moving objects using the hands. This model, also known as Fitts' law, sustains that the time necessary to select a target is proportional to the distance to the target and the size of it (Sears, 1989). Fitts' Law resulted to be a remarkably useful tool within HCI since one of the main aspects of this research area is the interaction between the user and different objects displayed on the computer's screen. This model is applicable to any user interface that requires an object to be selected in order to interact with it. This means that Fitts' law is valid for both traditional interface, based on the use of a pointing device like a mouse, as well as touchscreen interface, where the user simply points with the finger directly on the object to select it.

In order to increase the usability of a computerized system the designers must create an effective interface so that the user will be able to readily and rapidly select and manipulate the objects being displayed on screen. In general terms Fitts' law shows that the time needed for selecting a particular target on screen will be longer as the target's size gets smaller and vice versa. Likewise, the time necessary for selecting a target will be longer as the distance between the cursor and the target is bigger. Sears (1989: 20) explains that although this model works properly for traditional mouse and touchscreen-based interface there is an important factor to take into consideration: when using a pointing device, such as a mouse, users must first find the position that the cursor has on the screen (in this case the mouse arrow) and then drag the cursor towards the target in order to select it. When using touchscreen-based interface, however, the cursor is only activated when the user places the finger on the screen and since the logical thing to do is to place the finger right over the target then, when using touchscreen, the distance between the cursor and the target will be, at least in most cases, close to zero. Sear proposes therefore that Fitts' law requires a few modifications when analyzing touchscreen-based human-computer interaction: the distance factor should be a function of the physical distance between the hand laying in resting position and the screen itself. Regarding the size of the target and just like in the traditional interface, the time needed for selecting and object using touchscreen will be longer as the target's size becomes smaller. Figure 1 shows how the time variable is affected in relation to distance and size.

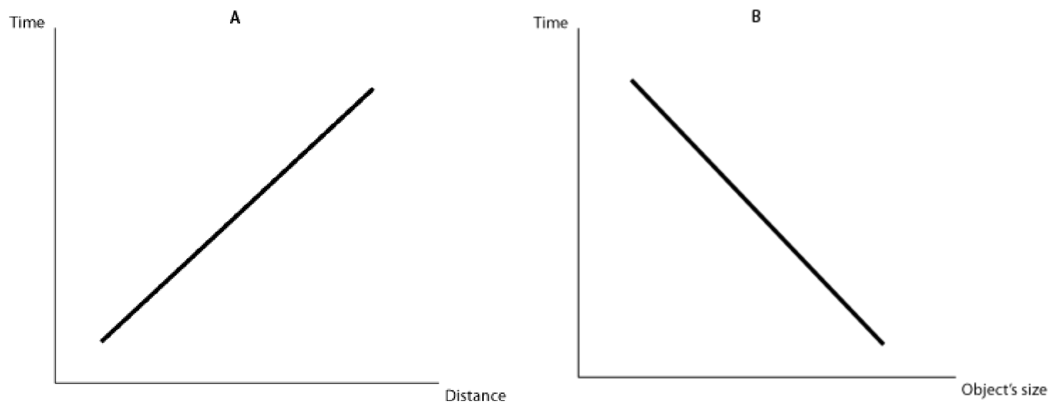


Figure 1: Graph A shows that distance is directly proportional to time according to Fitts' law.
Graph B shows that object's size is inversely proportional to time according to Fitts' law.

2.3.1 Previous research comparing touchscreen with mouse for selecting objects

Andrew Sears and Ben Shneiderman (1989) at the University of Maryland, conducted an observational experiment to analyze the main differences in terms of time and error rate between the traditional mouse as a pointing device and touchscreen interface. The tasks included the selection of objects of different sizes, some of them being only one pixel across. Having this in consideration it was decided to use lift-off selection strategy since it is more suitable for high-resolution tasks, which involve high precision cursor positioning.

The experiment consisted in having thirty-six participants with different experience level regarding usage of personal computers. Almost none of them had any previous experience with touchscreen-based interface. They were asked to execute a list of tasks that consisted in selecting square shaped objects of different sizes: 32, 16, 4 and 1 pixels across. The participants performed the same list of task twice: one time using a traditional mouse as a pointing device and the other time using touchscreen interface. The objects would appear randomly in one of the four corners of the screen and participants had to select them by moving a cursor in shape of a plus sign '+'. When using the mouse the selection would be made by draging the mouse until the center of the cursor would be placed over the target and then clicking. When using touchscreen the selection would be made by placing the finger over the screen and then dragging it so that the cursor would be placed over the target and then lifting the finger from the screen to make the selection. When the participant managed to successfully select the object or five errors were made without being able to make the selection then the object would disappear and a new one would appear on the screen.

This study showed that regarding selection time touchscreen interface was faster than traditional mouse when selecting targets with a size of 32 and 16 pixels across. With an object size of 4 pixels the mean selecting time was almost the same for both interfaces (touchscreen being roughly four tenths of a second faster than mouse). With an object just one pixel across, however, the mean selecting time become remarkably longer when using touchscreen interface, being about twice as long as when using traditional mouse. In relation to the mean error rate this study indicates that the measurements in this respect show a quite similar pattern. When selecting objects 32 pixels across participants using touchscreen interface made in average around four times less errors than when using traditional mouse (although in both interfaces the error rate was extremely low). With objects 16 pixels across the mean error rate was identical for both interfaces. When selecting objects 4 pixels across then touchscreen interface shows higher error rate than mouse. This tendency becomes even more extreme when selecting objects just one pixel across in which case participants using touchscreen interface show a mean error rate almost nine times higher than traditional mouse. Having these results into consideration it becomes clear that even if touchscreen interface outperforms traditional mouse when selecting big objects, its performance becomes rapidly deteriorated, both in selecting time and error rate, as the objects become smaller. Thus it is crucial to improve touchscreen interface in order that it will allow users to easily and rapidly be able to select objects on screen regardless their size.

2.3.2 Typing on touchscreen keyboards

Data entry is without a doubt one of the most crucial factors regarding HCI. People need to constantly register and store different sort of information, from the mobile phone of a friend to writing down the grocery list. Although the advances in interface technology have led to the creation of sophisticated interface systems like voice recognition, the fact is that typing is still the main way in which we introduce data in our computerized systems. Touchscreen-based interface must therefore be able to deliver an effective way to let the users type using this interaction mode easily and rapidly enough in order to be able to compete with the traditional interface based on physical QWERTY keyboards. Sears (1991) mentions that even if according to many studies touchscreen keyboards have showed to be slower than physical ones, there are cases where using touchscreen keyboards for short data entry may be particularly useful. He mentions that there are many applications that might require rather infrequent data entry and that having a physical keyboard in this cases is nothing but a big waste of otherwise useful working space on the desk. A virtual keyboard appears on screen only when needed, giving space to other more suitable interfaces when needed. The author also mentions the much higher flexibility that a touchscreen keyboard offers since the user can easily customize it in terms of size, shape, keys disposition and even the language of the keyboard including special characters, something entirely impossible to do in a physical keyboard (Sears, 1991: 2).

As mentioned in previous sections concerning ergonomics, the mounting angle of the monitor plays a crucial role regarding typing speed and error rate. An unsuitable angle would not just imply a worse typing performance but also an extra physical stress that will lead to arm and hand fatigue, making the whole experience unpleasant.

2.3.3 Previous research comparing typing performance between touchscreen and physical keyboard

Andrew Sears (1991) at the University of Maryland conducted an experiment that had for purpose to compare typing speed and error rates between a touchscreen virtual keyboard and a physical QWERTY keyboard. The experiment measured the performance of nine participants, all of them having plenty of experience using computers with traditional keyboard and mouse. Their experience with touchscreen, however was much more limited. The computer used for the experiment had both touchscreen and a retractable traditional keyboard. The touchscreen was designed to work with the land-on selection strategy (see section 1.1.2.2 for more information on touchscreen selection strategies). The participants were aided by both audible and visual feedback so that they could readily know when they had made a successful entry in the touchscreen keyboard.

The actual test consisted in making the participants type six strings of 6, 19 and 44 characters using touchscreen keyboard and a physical one. The researchers would measure elapsed time and error rates for each interface. Another aspect analyzed by Sears and his team was the preferred angle that the participants used while typing on a touchscreen keyboard. The results showed that regarding the average time needed by all the participants to complete the typing of the six strings of text was roughly 1.4 times longer when using touchscreen keyboard compared to a physical keyboard. This is a quite significant result since it means that physical keyboard is more than twice as fast as touchscreen keyboard. Regarding the error rate, the average error made by all participants, both corrected and uncorrected, was 1.4 for the physical keyboard and 1.8 for the touchscreen. In this aspect again is the performance of physical keyboard better than touchscreen interface. Finally, in relation to the preferred angle that participants used while typing on the touchscreen keyboard, this was around 30 degrees counting from horizontal.

2.4 The action-gesture relationship

The importance of gestures was already mentioned in section 2.2, but so far no definition of what a touchscreen gesture is has been presented. Saffer (2009) enumerates some characteristics that determine an interactive gesture, and thus separate gestures from just movement. These characteristics englobe several aspects such as duration, position, motion, pressure, size, orientation, number of touch points/combination, sequence, number of participants, etc. He points out that a basic touchscreen interface would involve less of those characteristics while a more sophisticated touchscreen interface would involve more of them. Saffer explains that a touchscreen gesture is an action started by a fingertip touch event, that the computer recognizes and then performs a specific task, which is already associated with that particular gesture. Furthermore, Saffer mentions that there are simple gestures and more complex gestures and that " the complexity of the gesture should match the complexity of the task at hand " (p.28). He also gives examples of different common gestures: tap to open/close, tap to select, drag to move object, slide to scroll, spin to scroll, pinch to shrink and spread to enlarge, two fingers to scroll, to rotate two fingers for rotating an object, etc. Saffer also talks about interface conventions, where he explains what problems a gestural interface like touchscreen would have when performing common actions used in the traditional keyboard-mouse interface. Actions like selecting, drag-and-drop and scrolling work well with gestures, but other actions like double click, right click, hovering over drop down menus, cut and paste, undo, etc. could cause problems when one attempts to perform them using touchscreen gestures.

Like many other areas within HCI, even the relationship between gestures and actions is not dominated only by one single stream of thoughts, such as Saffer's view on it. As already mentioned in section 2.3 regarding Fitts' law, Andrew Sears and Ben Shneiderman (1989) talk about selection based actions rather than gestures and Brolin (2006) makes a separation between gesture-based actions and other sorts of actions consisting on simpler moves, as mentioned in the previous section about body usage within HCI. One could either consider all touchscreen-based actions as gestures or eventually categorize these actions into gesture-based actions and other type of actions like selection-based actions. Using Sears' study of touchscreen-based selection actions as reference, common actions in this category would be: tap/double tap, tap to select one object, tap and drag to select multiple objects, drag to move object, etc. (figure 2 and 3 are examples of this type of actions). On the other hand, examples of gesture- based actions, using Saffer's approach would then be: slide to scroll, pinch to shrink and spread to enlarge (zoom in/out), two fingers spin to rotate, etc. (as shown in figures 4).

Figure 2: Tapping on an object and then dragging it into a window.

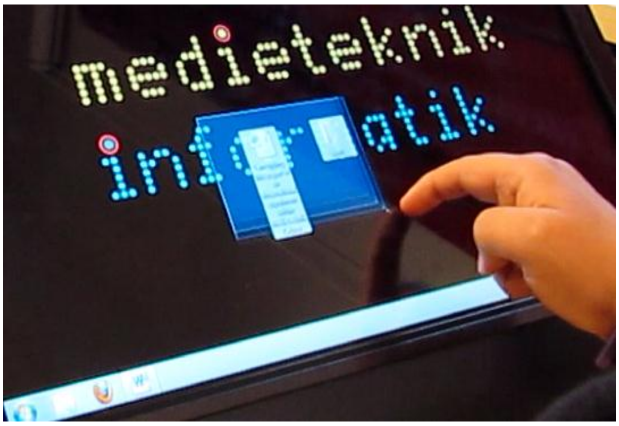


Figure 3: Tapping and then dragging the finger to select two icons

a)

b)

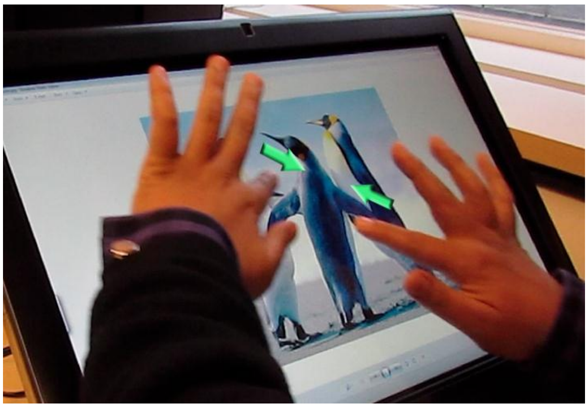


Figure 4: Picture a) shows gesture for zooming in a photo; the arrows show the direction of the fingers' movement. Picture b) shows zooming out the photo; here the direction of the fingers' movement is reversed.

3. METHODOLOGY

3.1 Selected method

Two methods have been selected for the realization of this study: observations and interviews. The data collection included both quantitative and qualitative aspects during the research. The following is a brief explanation about both methods and the data collected through them.

3.1.1 Observation

According to Judith Bell (2010), an observation is usually seen as a qualitative empirical approach, but it is possible to gather even quantitative information through it. She points out that observations are quite useful when one wants to know about what people really do or in which way they react in certain situations. More or less this is also being applicable to artifacts. The same author presents also different kind of observations that one can perform, such as structured and not-structured observations or participatory and not participatory observations. The kind of observation used in this essay is a structured and participatory observation. For structured observations, says Bell, that it is essential that the researchers have an already defined purpose, from which to start observing the subjects participating in the study. Participatory observations are described by Bell as very useful to get a good picture of the course of events through time when studying individuals' performance. Furthermore, since the researchers get closely involved with the subjects of the study, they must be careful not to lose their objectivity.

With the help of a task list and notational tables, data was collected. This collected data have mainly quantitative nature in form of time and error rate, but also a bit of qualitative nature in form of notations regarding interesting moments during the observation, for example, strategy chose by the participants when executing the tasks and the kind of errors they made. In addition, the entire observations were videotaped for further analysis. More about how the observations was organized and performed comes in section 3.5 regarding study realization.

3.1.2 Interview

Interviews are also presented by Bell as a part of the qualitative empirical approach, but it even gives a possibility to collect both qualitative and quantitative data. The main advantage of interviews, according to her, lies in the dialog between the interviewer and the respondent, which can give both direct information (such as opinions, feelings and others) and indirect information (such as body language and intonation). Another good feature of the interview technique is the flexibility it provides to the interviewer to follow up some ideas and sort the respondent's answers. Bell explains that, when performing interviews, an important thing to pay attention to is not to ask misleading questions to the respondents. Furthermore, she mentions three types of interviews: structured, semi-structured and unstructured. The type of Interview used in this essay is the semi-structured one. Bell mentions that semi-structured interview is useful because the researcher knows what kind of information to obtain from the respondent that will be useful for the study. The interviewer makes a list of questions that are going to be asked to the respondent, but a more open dialog can be developed between the interviewer and the respondent concerning a particular question, if that might lead to more detailed information.

A list of questions was made to be asked to the participants in this study and the recording of the answers was decided to involve writing down notes and voice recording, techniques that Bell mentions are the most common when performing interviews. More about how the interviews were performed comes in section 3.5.2.

3.2 Participants

A total of six people participated in the study. All of them volunteered to participate and also all of them fulfilled the two requirements established for being a suitable participant for this study: no previous experience with touchscreen technology within PCs and at least having some experience with Windows operative system. According to Bell the participants involved should be representative for the whole population for which the study is based on. Since there were only two simple criteria that the volunteers had to meet in order to be suitable for the experiment, no demographical issues were relevant to determine the population for this study. Users that don't have any experience with Windows operative system were excluded from the population.

3.3 Equipment

The hardware part of the equipment used in this study was a touchscreen capable all-in-one desktop personal computer that also included a physical keyboard and a mouse. The software part included Microsoft Windows 7 Enterprise operative system, Firefox Internet browser and Microsoft World 2010.

More specifically, the computer model used was the HP TouchSmart 610 (figure 5).

a) b)

Figure 5: Picture a) is a front picture of the HP TouchSmart 610 all-in one desktop PC

Picture b) is a side picture showing the different angles for the monitor.

This computer has a 23 inch LCD panel display using infrared beams-based touchscreen technology with a standard resolution of 1920 x 1080 (16:9 aspect ratio). The monitor can be adjusted, regarding the angle, from a vertical 90 degrees position until a 30 degrees position, counting from horizontal.

The two other hardware devices were:

- Zowie wired optical mouse with two main clickable buttons and a scroll button, plus two mini buttons on the left side, which are used for different operations, for example, go to next page or go back to previous page
- Logitech wired QWERTY keyboard of standard size with numeric keypad and Swedish alphabet.

The operative system was configured so that it could work in both traditional and touchscreen interface. This software features a virtual keyboard on screen that can be activated any time data entry is required.

3.4 Three main interface modes

The selected participants will have to execute a series of tasks using a computer in three different interface modes that will be described below.

Traditional interface: Whenever the term traditional interface is used in this study, it refers to the usage of a standard-sized physical QWERTY keyboard in combination with a physical double button mouse. The screen resolution when using this interface will be set to 1920x1080 pixels, which is the standard resolution used by Windows 7 Operative System for a 23-inch monitor.

Touchscreen running at standard resolution: This touchscreen mode will be used in a monitor set at a standard resolution of 1920x1080 pixels, which is the same one applied when using traditional interface. Neither physical keyboard nor mouse will be available when using this interface. The participant will rely solely on touchscreen interface to interact with the computer.

Touchscreen running at lower resolution: When using this touchscreen mode the monitor will be set at a lower resolution of 1360x768 pixels. Notice that when using this lower resolution everything showed on screen will look roughly twice as big as it does when using standard resolution. In figure 6 one can observe the clear difference in size of the objects showed on screen. In the picture on the left the monitor is working with standard resolution (the higher resolution) whereas the picture on the right is working with lower resolution. Notice that both the icons and the window are smaller in the left photo when using higher resolution, while the objects on the right photo showed at lower resolution are almost twice as big in area size.

Figure 6: The monitor on the left is running at higher resolution (smaller objects) while the monitor on the right is running at lower resolution (bigger objects).

3.5 Study realization

3.5.1 Observation

To begin with it is necessary to say that the observational experiment was performed with one participant at a time. A list of tasks was handed in to every participant. A short three minutes video was then showed to each participant explaining basic instructions for operating the HP computer with touchscreen interface. The video shows how to execute the tasks that the participants will later have to realize themselves. After the video the participants were given a few minutes so that they could practice on their own using the touchscreen in order to familiarize themselves with this type of interface since none of them had previously used a personal desktop computer with touchscreen. The subjects were asked to read in advance the task list so that they could ask any questions they could have regarding how to execute a particular task.

The participants had to execute a list of sixteen tasks (for a complete and detailed description of the entire task list see the appendix). The participants would be given a start signal to let them know exactly when to start. The stopwatch started then running and it would stop only when the person has successfully executed the task. If the person makes a mistake that completely ruins the normal course of the task execution then the stopwatch will be reset and the task will be performed again.

The list of tasks was executed three times in consecutive rounds. Each round using a different interface mode as detailed below (see section 3.4 for a more detailed description of each interface used). These were the interface modes used:

- Traditional interface: Using physical keyboard and mouse and a 23-inch monitor running at standard resolution.

- Touchscreen interface running at standard resolution: The resolution used in this interface mode is the same applied when using traditional interface. The monitor size is 23 inches for this interface too.

- Touchscreen interface running at lower resolution: The resolution used in this interface mode makes all objects displayed on screen to be roughly twice as big as they are when using standard resolution. The monitor size is 23 inches for this interface too.

All participants used traditional interface for the first round. The reason for this was to let participants get more familiarized with the tasks while using an interface mode that all of them had already used before. Regarding touchscreen-based interface there was a random selection in order to define which resolution configuration would come in the second and third round.

The participants were allowed to adjust the monitor angle before starting to execute any new task. Likewise they had the chance to ask every time before starting each task in case they had any question regarding how to execute it. The idea was that the participants would have as much information as possible during the realization of the experiment since the main aspect to be studied in this observation was the usability in terms of time and error rate of both, traditional and touchscreen interface. If a participant would get stuck in a particular task because of the only reason of not knowing how to perform it, that could completely distort our measurements of mean time and error rate, which in turn could give misleading results.

Regarding the cursor positioning two starting positions were determined for each of the two main interfaces. When using traditional keyboard and mouse the participants started the execution of each task having the cursor (the mouse arrow) placed in the very middle of the monitor. When using touchscreen interface, however, the cursor is only activated the very moment the participant puts the finger over the screen and thus the initial position for the participants before starting the execution of any task, while using touchscreen, was having their both hands resting over the desk. Determining a standardized initial cursor positioning for each task is essential in order to get reliable time measurement since, according to Fitts' law, one of the two main variables that determines the time needed for executing a particular task is given by the distance between the cursor and the object that is to be selected (Sears, 1989:20).

During the execution of the tasks the participants were videotaped. The notations done during the experiment was the elapsed time for the completion of each task plus some qualitative notations regarding any aspect that was considered to be noteworthy such as the strategy used by the participants to perform a particular task, any major difficulty that a participant could have experienced during the observation, etc. The recorded videos were then thoroughly analyzed to count error rates for each task. The whole observational phase took roughly an hour for each of the six participants.

3.5.2 Interview

The interview took place right after each participant had successfully finished the execution of the task list using the three interface modes. As already explained in section 3.1.2 the type of interview made for this research was the semi-structured interview, which will allow a dialog between the interviewer and the respondent so that the conversation can be guided towards the exact subjects and aspects that the researchers are wanting to analyze.

The main purpose with the interview was to get a qualitative insight regarding how the participants experienced their interaction with the computer using the different interfaces. The participants were asked to compare the different interfaces and mention positive as well as negative aspects about each one of them. Although the interview was intended to reach a better comprehension concerning the different interfaces used by the participants, the questionnaire had a little extra emphasis regarding touchscreen since this interface is the essential core of this research. The questions covered both traditional interface and touchscreen and the participant was asked about their opinions regarding both of them. The participants were also asked to compare both interfaces. The interview questionnaire comprised a total of eleven questions (for a complete and detailed description of the questionnaire see the appendix). All interviews were sound- recorded and the interviewers were making their own notations during the course of the conversation. Each interview took around 25 minutes to be completed.

3.6 Methodology for data analysis

For the analysis of the experiment's results that will be described in section 4 it is necessary to categorize the list of sixteen tasks that the participants executed during the observation. This categorization is essential in order to be able to analyze the measurements done (time and error rate) during the observation and to determine how they relate to Fitts' law and the previous research described in section 2. The sixteen tasks in the list involved the execution of many actions of different nature, where factors such as screen resolution and object's size have different repercussion levels depending on the type of the action in question. Although Saffer (2009: 3) regards every action that executes a predetermined task to be a gesture, in this study a slightly different categorization of action types is going to be made, merging the ideas of Saffer and the experiments conducted by Andrew Sears. The following is the categorization of tasks made for this research.

Selection-based actions

This type of actions requires the users to select a certain object that has a certain size on screen. The selection will be made by whether clicking on the object with the arrow cursor, when using a physical mouse, or by tapping with the finger directly on it, when using touchscreen interface. The following actions can be considered to belong to this category: tap/double tap to open/close a window, tap to select an icon or file, drag to move an object, tap and drag on windows border to resize, etc. In this type of actions the size of the object to be selected affects the error rate and therefore the time needed for executing the task successfully (as already explained by Sears concerning Fitts' law in section 2.3). These types of actions can be performed using both traditional and touchscreen interface and therefore clicking and tapping are actually the same action. The term depends on which interface is being used (touchscreen or traditional). During the observation and analysis of the experiment, an error will be considered to be any failed selection whether when not being able to select any object at all or when selecting an object that was not supposed to be selected.

Gesture-based actions

In this study a gesture-based action, when using touchscreen interface, is any action executed by performing a certain gesture with the hand, when interacting with the computer (see section 2.4 for more details on gestures). These gestures can be of different nature and they can be executed using one or more fingers at the same time. Since gesture-based actions do not imply the selection of a certain object displayed on screen then the size of the objects has no major repercussion in the error rate and time required for performing this type of actions. Common gesture-based actions can be rotating a photo or any other object by spinning two fingers, zooming in or out by doing a pinching or spreading move with two fingers, scrolling up/down or left/right by sliding one or two fingers in those directions, swiping with the finger left or right to browse among photos, etc. A very particular characteristic with gesture-based actions is that they can only be performed using touchscreen interface. During the observation and analysis of the experiment, an error will be considered to be any gesture made by the participant that was not recognized by the computer or when the gesture performed something different than the action that was originally intended.

Typing-related actions

This is the last category of action that will be analyzed in this study. Typing involves the entry of data by using a keyboard, whether physical or touchscreen-based. Within typing-related tasks an error will occur every time the participant hit the backspace key to correct. In addition, the amount of uncorrected errors in the final text will also be counted.

The comparison of the three interface modes used in the experiment will be done in the following fashion:

- Traditional interface compared to touchscreen interface, both running at a standard resolution of 1920x1080 pixels, meaning that the size of the objects showed on screen will be the same for these two interfaces.

- Touchscreen running at standard resolution (1920x1080 pixels) compared to touchscreen running at lower resolution (1360x768 pixels). Lower resolution implies that the objects showed on screen are bigger than in standard resolution.

In order to obtain a reliable result in relation to the number of errors made by the participants during the observational experiment it is required to have a clear definition of what is to be considered as such. In this study an error will occur any time when the participant fails to select a certain object on screen. Likewise, any unintended touch (any touch input done by unintendedly tapping on the screen) will be counted as an error. Misspelled words (both corrected or uncorrected) in the typing-related tasks will also be considered as an error. Regarding gesture-based actions an error will occur any time the participant fails to execute the desired action, whether because the computer did not recognize the gesture or because the computer executed a different action than the intended one. In cases where the normal execution of the action is completely ruined and taken into a different direction, for instance when the participant opens a program or a photo that was not supposed to be opened, then the stopwatch will stop and be reset to start the execution of the task all over. This is done in order to avoid distorting the calculation of the average error and time in case the participants make a mistake that would take them too long to fix, which in turn can lead to the realization of even more errors.

Finally, regarding the processing and analysis of the measurements of time and error rate in the observational experiment, the main mathematical tools used for this purpose was total sum as well as average value for time and errors. The entire set of graphs showing the results for each of the sixteen tasks performed by the participants is shown in the appendix.

The interview part of the study aimed to get a better insight about two main issues: a comparison of the traditional interface and the touchscreen interface as well as a deeper review of the touchscreen interface regarding some important topics like typing and the size of the objects. The main method used for the analyses is generalization by grouping together the participants' answers to the questions into major topics based on concepts from the literature and the previous research already described. If in a particular question there are answers that are recurrent among all the participants, then they will be grouped together in a general theme that will have high relevance for the final conclusions, while less recurrent answers will be regarded as an individual aspect (aspects that only one participant mentioned). All the data regarded as individual aspects will have lower relevance for the final conclusions since they do not represent the vast majority of the participants' opinions.

Two of the questions involve some level of quantification. One of these questions requires the participants to grade each interface used (see the questionnaire in appendix), then for this question the usage of average value as a tool is needed.

3.7 Method criticism

Like in any study, there are a series of topics regarding the methodology used that can be subject of certain level of criticism. There are three main aspects worth to be mentioned regarding the way in which the experiment was performed in this study.

The participants executed the task list three times in a row: The participants had to perform the entire list of task three consecutive times, each time using a different interface. It was decided that the first interface that the participants would use in the experiment would be the physical keyboard and mouse. This was decided in order to give the chance to the participants to get familiarized with the different tasks while using an interface that all of them had plenty of previous experience with. The order in which the two touchscreen interface modes would be used by the participants was decided randomly. As the participants execute the consecutive rounds of task lists they learn and get ever more familiarized and skillful when performing the tasks. It is, therefore, reasonable to think that this might have some repercussion in the time and error rate measurements done during the execution of the three consecutive rounds of task lists. That is the reason why after using traditional interface the other two touchscreen interface modes were assigned in a random order. In order not to give an unintended advantage to one particular touchscreen interface mode over the other.

A fairly small number of participants: A total of six volunteers participated in this experiment. When measuring the performance in terms of time and error rate of a somewhat small number of participants, the differences that each participant shows in terms of these two variables can eventually affect the results of average value. It was expected that, regardless the interface used, there could be some differences in terms of time and error that are only due to the fact that people have different levels of motor skills and abilities to execute different types of tasks. The participants were told to perform the tasks fast, but they were also instructed not to go beyond their own limits of speed since this might provoke that they get nervous and overstressed, which in turn could get them make more errors and thus the experiment could get less reliable results. The number of participants was determined having into consideration the limitations in terms of time and resources.

The participants used different strategies: A certain level of freedom was given to the participants when performing some of the tasks in the list. This might have some repercussion in the measurement of time and error rate since the participants could, sometimes, perform a certain task in a slightly different way than the rest of the participants. The idea behind giving some level of choice to the participants was due to the fact that one of the many aspects that was to be analyzed in this research is how people behave and choose to interact with the computer given different types of tasks and activities. The difference in measurements in this respect are, nevertheless, expected to be very marginal since only a few tasks were possible to be performed in more than one possible way.

4 RESULTS AND ANALYSIS

4.1 Observations – comparing the three interface modes

As previously mentioned, the observational experiment measured two main quantitative variables: elapsed time for performing each task and error rate during the execution of each one of them. The following is a summary showing the main findings of the experiment conducted (for more detailed information on the measurements for each task regarding time and error rate see the appendix).

4.1.1 Total time and error rate of each interface for all tasks

To give the most general comparison between the three interfaces and how they performed in terms of time and error rate for all the tasks executed, two bar graphs will be presented. Figure 7 shows the total time required by all the six participants put together to complete the list of sixteen tasks, for each interface. The traditional interface (physical keyboard and mouse) showed the shortest time needed for completing the tasks, whereas touchscreen used with smaller objects on screen (standard resolution) showed the longest time, taking the participants 64% longer using this interface, in comparison with traditional interface.

Taking now only the two touchscreen resolution modes into consideration, standard resolution touchscreen (which shows smaller objects on screen) showed a longer time needed to perform the tasks, in comparison with touchscreen running in lower resolution (which shows bigger objects on screen), being standard resolution touchscreen roughly 9% slower than touchscreen in lower resolution.

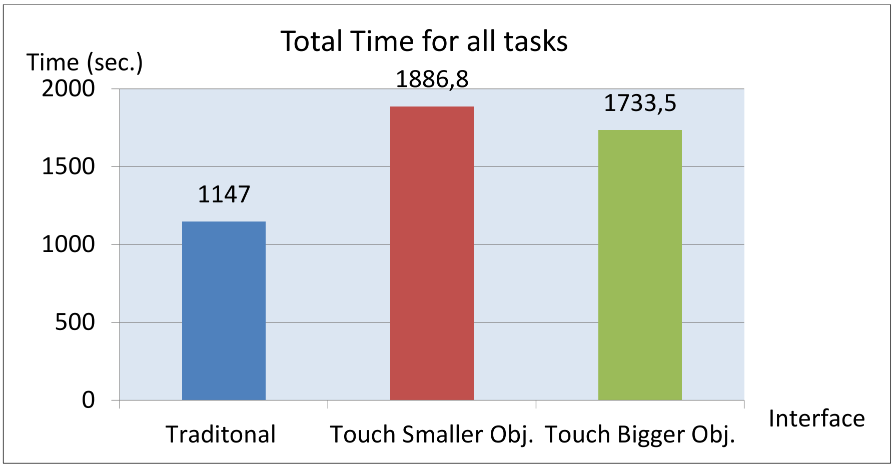


Figure 7: Total time needed by all participants put together to complete the entire task list.

Figure 8 shows the total errors made by all participants put together while executing the task list. The error rate using traditional interface was significantly lower than the error rate observed while using the other two touchscreen interface modes. In contrast, the interface that showed the highest error rate was the touchscreen showing smaller objects on screen, having this interface mode an error rate almost 7 times higher than traditional interface. Regarding solely the two touchscreen modes, the standard resolution mode (smaller objects on screen) proved to have an error rate approximately 1.4 times higher than touchscreen used with bigger objects on screen (lower resolution mode).

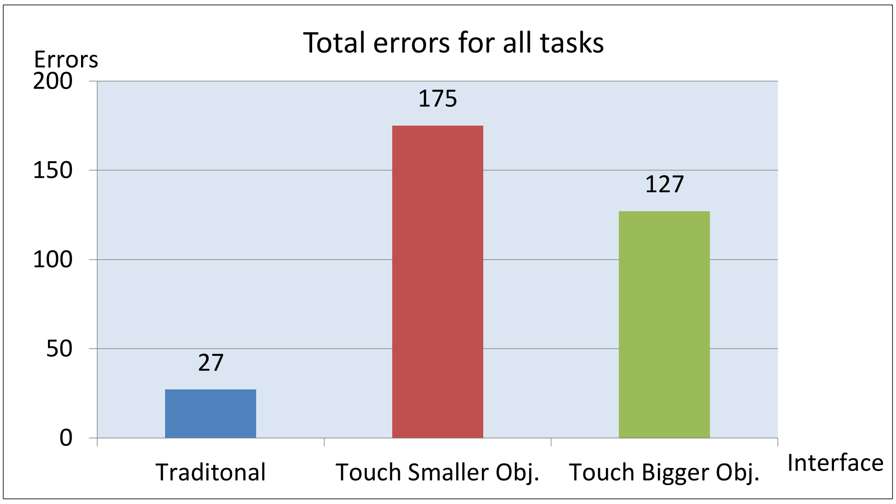


Figure 8: Total amount of errors made by all participants put together for completing the task list.

When observing figure 7 and 8 the relation between time and error rate becomes clear. The time needed for executing a particular task will become longer as the user makes more mistakes before achieving a successful execution of that task. The touchscreen displaying smaller objects on the monitor (standard resolution) shows the worse performance regarding both error rate and time, whereas touchscreen showing bigger objects on screen (lower resolution) had fewer errors and therefore a shorter time needed to perform the tasks. Nevertheless, the interface showing the lowest error rate and thus the shortest time for completing the task list is the traditional keyboard and mouse. That is why when observing the graphs for time and error rate regarding most of the tasks these graphs will tend to show the same pattern: traditional interface showing the best performance while touchscreen with smaller objects shows the worse performance. Touchscreen showing bigger objects had therefore a better performance than touchscreen showing smaller objects but worse than the traditional interface.

4.1.2 Total average time and average error rate for each task in relation to Fitts' law

When one analyses the average time for each particular task (see appendix) one can easily recognize that there is a pattern that repeats in many cases: traditional interface performs better than touchscreen showing smaller objects while touchscreen showing bigger objects performs better than touchscreen with smaller objects, but worse than traditional interface. This pattern is present in about 63% of the sixteen tasks. Traditional interface tended to be the fastest since all of the participants had plenty of experience with it and were already familiarized with using physical keyboard and mouse. Touchscreen-based interface for personal computers was, however, something completely new for all the participants and that is one of the reasons, although not the only one, why this interface mode showed worse performance than traditional interface. These results were actually expected when having Fitts' law into consideration. As mentioned in section 2.3 there are two factors that determine the time needed for completing a task: distance from the selecting cursor to the object and object's size. The distance between the cursor and the object to be selected does not represent a substantial differentiator due to the fact that there was a common starting position for the cursor (mouse arrow in the middle of the screen when using mouse and hands resting over the desk when using touchscreen, as explained in section 3.5). This means that the distance between the cursor and the objects to be selected was rather similar for all the sixteen tasks and thus it did not affect the time measurements substantially. The size of the objects to be selected has, on the other hand, a significant influence in the time needed to execute each task as well as the error rate. That is one of the main reasons why, when comparing both touchscreen modes, one showing bigger objects on screen while the other was showing smaller objects, the time measurement for each task tended to be shorter for the first touchscreen mode and longer for the latter. The same was observable regarding error rate: touchscreen showing bigger objects had a lower error rate than touchscreen showing smaller objects on screen. This pattern was observable in about 68% of the cases, showing a great similarity with the time measurements. In only about 32% of all cases observed was this pattern altered. Fitts' law is thus valid in roughly two thirds of all the cases observed.

4.1.3 Selection-based actions versus gesture-based actions

When describing the methodology (section 3.6) it was established that the tasks performed by the participants were to be divided into three main categories: selection-based tasks, gesture-based tasks and typing related tasks. This division was made in order to be able to determine how applicable Fitts' law can be to different types of tasks. This section is going to focus in selection-based and gesture-based tasks only. For the analysis of the typing-related actions see the following section.

The observational experiment comprised a series of sixteen tasks, some of them involving one single action to be performed, some others englobing a combination of tasks of different nature. In this section those tasks from the list that involve the execution of a combination of actions of different nature will be excluded. The list below is a selection of tasks that involve the execution of actions of one single nature only (see the list of tasks in the appendix to see a description of each one of them). These tasks were categorized, depending on their nature, as follows:

- Selection-based tasks: 1-a, 1-b, 1-c, 2-c, 3-c, 5-a.
- Gesture-based tasks: 4-b, 5-b, 5-c, 5-d.

In section 4.1.2 it was mentioned that Fitts' law was valid for roughly two thirds of the cases regarding both time and error rate. That is the reason why the pattern mentioned previously tends to repeat: traditional interface shows the best performance, touchscreen showing bigger objects came in second place and touchscreen showing smaller objects tended to show the worse performance Having this task categorization into consideration it is possible to notice that, unlike selecting-based actions, gesture-based actions are not particularly affected by the size of the objects on screen. From the four gesture-based actions mentioned in the list above none of them show the described graph pattern regarding time. On the contrary, all the six selection-based actions in the list above show the pattern described when observing the graphs of average time and error rate.

It was already mentioned that traditional interface tended to be the fastest and show the least error rate due to the fact that all participants had plenty of experience using this interface. However, regarding solely the two touchscreen modes used, the reason why the pattern becomes altered among gesture-based actions is that objects' size do not have an effect in the time needed for executing the action since these kind of actions do not imply the selection of an object on screen, thus Fitts' law's validity does not completely apply for gesture-based actions. Two different actions, one being a selection-based and the other being a gesture-based action will be analyzed to better illustrate the difference between them and how they relate to Fitts' law.

Selection-based actions: Task 1-c is a selection-based action where Fitts' law's validity becomes readily noticeable. This task was to click/tap on the lower right corner of a window and drag outwards and then inwards in order to resize it (see figure 9). As the graphs show, regarding average time the fastest interface was the traditional mouse, whereas both touchscreen interface modes required longer time for performing the task. One of the advantages that traditional interface has compared to touchscreen is the fact that the cursor's precision when using mouse (the mouse arrow) is as high as to allow users to click on a single pixel on the screen. Notice that the error rate using traditional interface in this task was close to zero. When using touchscreen, however, the selecting cursor (which in this case is the human finger) is considerably less precise, being significantly difficult selecting objects smaller than 4 pixels across.

When comparing solely the two touchscreen modes the repercussion that the size of the object has in the time needed for successfully performing the action is patent. The average time needed for the six participants put together when using touchscreen with smaller objects on screen was approximately 41% longer than the time needed when using touchscreen with bigger objects, for this task. Notice how significant the difference between these two interfaces is concerning error rate (see appendix for this task graph). Touchscreen with smaller objects (standard resolution) had an error rate more than twice as high as that showed when using touchscreen with bigger objects on screen (lower resolution). The border of the window that had to be resized for this task was 2 pixels across when using the monitor at standard resolution and 4 pixels across when the monitor was running at lower resolution and therefore the error rate for touchscreen with smaller objects was roughly 124% higher than that for touchscreen showing bigger objects. Fitts' law's validity is thus evident in this task as well as the other selection-related actions.

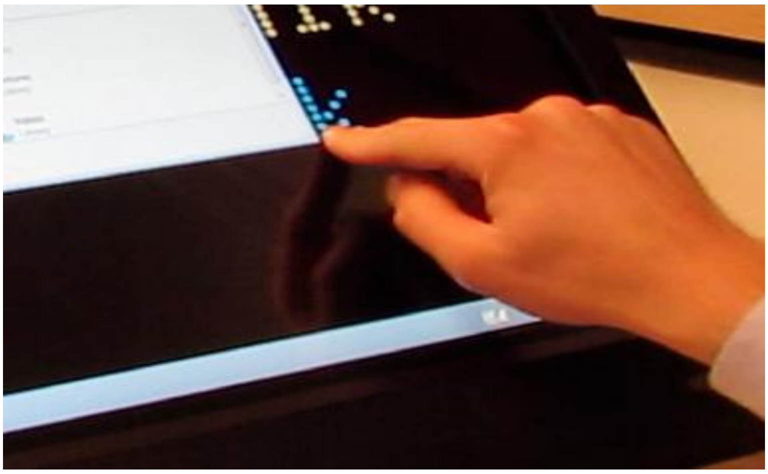


Figure 9: tapping on a window’s lower corner to resize it is a selection-based action that proved to be quite a challenge when using touchscreen in standard resolution (smaller objects on screen).

Gesture-based actions: As already mentioned, this type of actions does not involve the selection of an object on screen and thus neither the size of the objects nor the resolution of the screen have a direct repercussion in the time needed or the error rate. Task 5-c is a good example to illustrate gesture-based actions. In this task the participants had to rotate a photograph. To do so they had to click in the proper rotating tool button when using traditional interface or perform a gesture using the fingers on the screen when using touchscreen interface (see figure 10). This gesture is performed by doing a rotational movement using two fingers, commonly the thumb and the index, although it can also be performed using two hands. It is worth noticing that, as already mentioned, gesture-based actions can only be executed by using touchscreen interface and thus when rotating the photograph using traditional mouse and keyboard this is not considered to be a gesture.

When one examines the bar graphs of time and error regarding this task one can notice that the usual pattern observed in the selection-based actions is altered. This is due to the fact that the size of the objects on screen becomes somewhat irrelevant and therefore Fitts’ law is not applicable in gesture-based actions. Something indeed interesting in this particular task is the fact that, regarding the average time, traditional interface did not show the best performance, as it is the case in most of the task list. The best interface in this case (the one that showed the shortest time) was touchscreen with smaller objects (standard resolution). The reason why touchscreen had a better performance in terms of time could be the fact that, for this type of actions, touchscreen interface and particularly the usage of gestures for executing a certain task are actually easier, more intuitive and thus faster than traditional mouse where the user has to locate the proper rotation tool on screen and then select it, whereas when using gestures the user must not select any particular object but only do a simple gesture with the hand over the screen

Comparing now only the two touchscreen modes the graphs show that, regarding both time and error rate, touchscreen with bigger objects had worse performance than touchscreen showing smaller objects. More accurately, the time needed by the participants to perform this task was approximately 35% longer with touchscreen showing bigger objects compared to touchscreen showing smaller objects. Likewise, the error rate was dramatically higher with touchscreen showing bigger objects, being 5 times higher than touchscreen showing smaller objects. This fact suggests that, regarding gesture-based actions, having bigger objects on screen does not necessarily imply that the time needed for performing the action will be shorter, nor that the error rate will be lower, as Fitts' law proposes.

If the size of the objects does not represent a crucial factor that determines time and error rate then, what is the reason that explains the different results between the two touchscreen modes regarding gesture-based actions? The reasons can be many and of diverse nature. The sensitivity of the screen can have a great deal to do regarding how good or bad the computer recognizes the gesture and this is strongly related to the type of touchscreen technology used in the monitor (see section 1.1.2.1 to see more details on types of touchscreen technologies). Another possibility has to do with the materials used to build the screen and in particular the surface where users slide their fingers. Some sorts of plastics make it relatively difficult to slide the fingers across the monitor's surface smoothly and seamlessly. Another yet possibility is that the user is not performing the gesture properly and therefore the computer fails to recognize it.

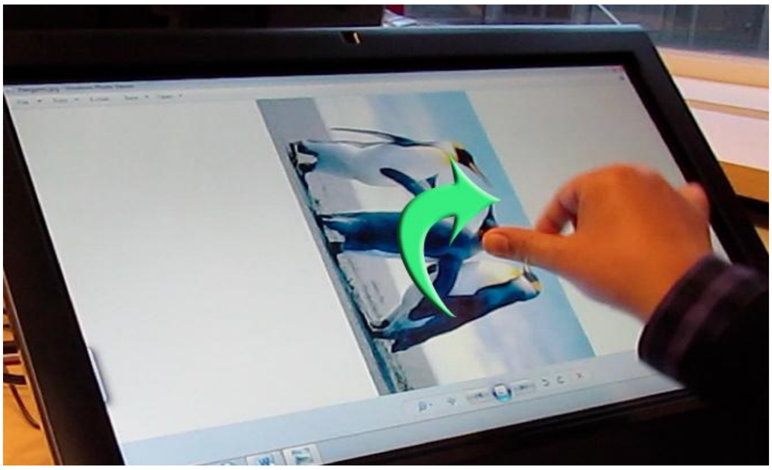


Figure 10: Rotating a photo using touchscreen interface by doing a rotational move with two fingers is a typical example of gesture-based actions. The arrow shows the direction of the rotation.

4.1.4 Typing-related actions

In this section the main comparison is going to focus on traditional interface (physical keyboard) and touchscreen interface. Since the virtual keyboard used with touchscreen can be resized by the users to suit their preferences, no major analysis comparing both touchscreen modes will be done, due to the fact that no matter the resolution used (and therefore the size of the objects) the touchscreen keyboard used had virtually the same size in both touchscreen modes.

Figure11 shows the virtual keyboard used during the observational experiment. When typing on a touchscreen keyboard, ergonomic factors play a central role determining both time for typing a certain text and the error rate. The angle of the monitor is essential to determine the level of fatigue and physical stress that users will experience in their hands and arms while typing. All of the six participants chose an angle of around 30 degrees counting from horizontal, which is close to the limit of the monitor's inclination that the computer used in the experiment permits.

Figure 11: Touchscreen keyboard can be somewhat difficult to use due to the lack of physical keys that help knowing where one has the fingers over the keyboard.

Unlike the physical keyboard where the users can touch and feel each one of the keys, on the virtual keyboard, however, the users cannot have a feeling of what keys they are pressing just by relying on touch, since the user is touching on the monitor's surface which is utterly flat. In addition, there is no physical sound when activating the keys on a virtual keyboard, unlike the traditional keyboard. Both the touch of physical keys and the sound they make when pushed help the user to rapidly and easily find the keys. The computers used in the experiment had some aids like changing the color of the key when touched as well as using an electronic sound to help users know when they made an input. Nevertheless the general performance regarding both time and error rate was considerably better when using traditional physical keyboard.

Taking task 2-a into consideration (see task list in the appendix), since this task involved typing only, one can observe that the difference between traditional and touchscreen showing smaller objects is considerably big. We compare traditional interface with this touchscreen mode since both of them were running at the same resolution level. Figure 12 shows that the average time needed by the participants to type in the text using the touchscreen keyboard was roughly 80% longer than the time needed when using traditional physical keyboard.

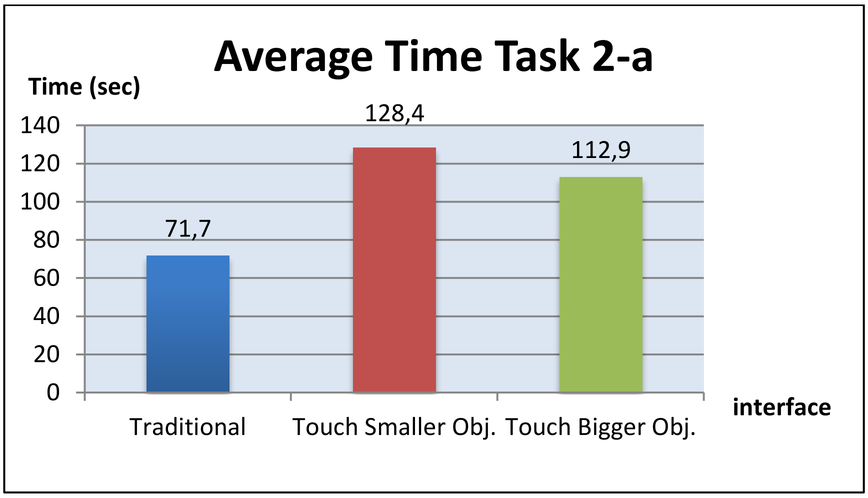


Figure 12: The average time for typing in the entire text was approximately 80% faster when using traditional physical keyboard, compared to touchscreen keyboard.

As described in section 3.5.1 the errors for this task were measured both while participants were typing in the text and in regard to the amount of mistakes observable in the final text that were not corrected. Regarding error rate observed during the typing of the text, physical keyboard also showed better results having approximately 60% less errors than touchscreen keyboard, although in both interfaces the error rate was rather low (figure 13). Concerning the errors observable in the final text (figure 14), the graph shows a slight variation: the average amount of errors, in this case, was actually higher for the traditional keyboard and lower for touchscreen interface. The reason found for this peculiar result is that, when using traditional keyboard, the participants tended to write faster and apparently less carefully. This can be attributed to the fact that all participants had previous experience with physical keyboards, whereas regarding touchscreen keyboards they were much less familiarized with them and thus they were typing more carefully and they were able to correct the mistakes while typing in the text.

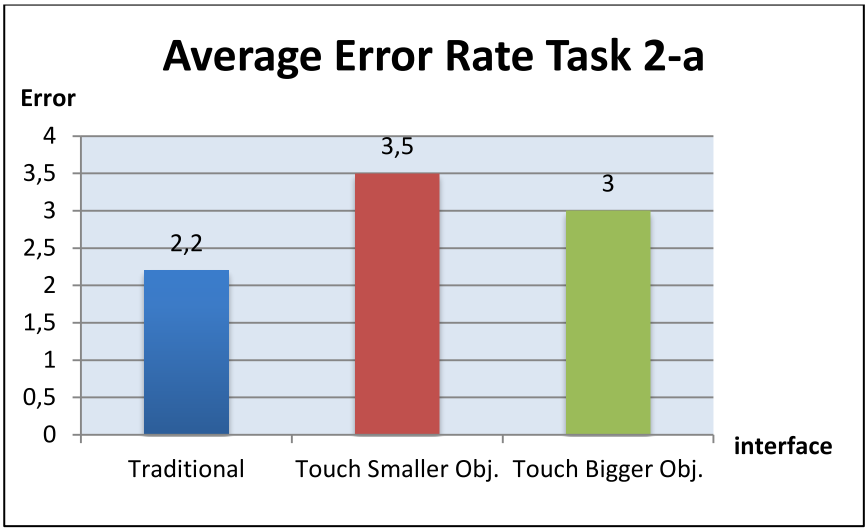


Figure 13: The average error rate, although rather low in all cases, was roughly 60% higher for touchscreen interface compared to physical keyboard, when counting the errors made during the typing of the text.

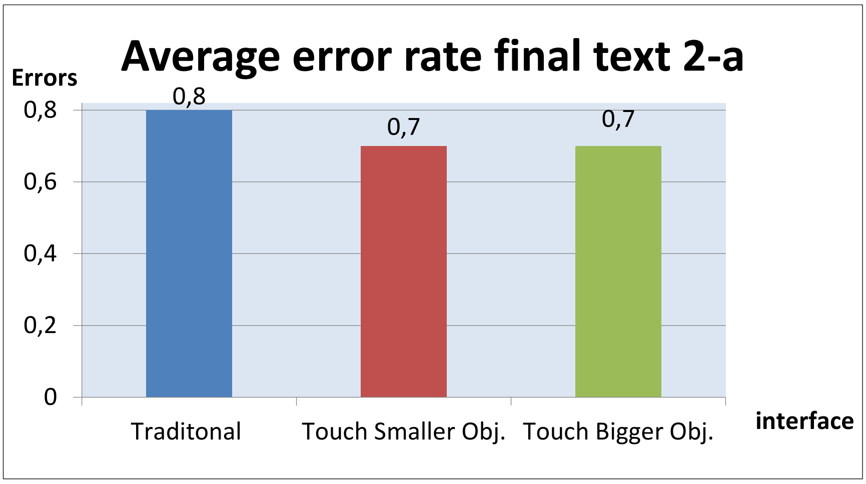


Figure 14: The average error rate observed in the final texts, although very low in all cases, was actually higher for the traditional physical keyboard.

It is worth mentioning again that the participants were well familiarized with typing on physical keyboards while their experience with typing on touchscreen keyboard was mostly limited to touchscreen on mobile phones only. This factor must not be ignored as one of the reasons of why physical keyboard had a much better result, especially in terms of time. Yet, the factors mentioned above regarding ergonomics had, without a doubt, a strong repercussion as well.

Finally, in relation to Fitts law and how the objects' size influence the time needed for performing the action, typing on a touchscreen keyboard is indeed affected by this law since typing in essence involves the selection of keys that have a certain size. Making the keyboard's size smaller implies that the general time needed to successfully type a text might tend to become longer and the error rate higher. The difference in the results shown by the two touchscreen modes is rather little and since the participants could change the size of the virtual keyboard, the size of the keys did not represent a significant factor of analysis in this experiment, concerning this particular task.

4.2 Interviews

The importance of the interview part is that it gives idea of the users experience of what differences there are between the touchscreen interface and the traditional (keyboard- mouse) interface and to determine problematic areas with the touchscreen interface. The first set of six questions is about a comparison between the touchscreen interface and the traditional interface in terms of negative and positive aspects and the users rating of each of the interfaces. The second set of four questions focus only on the touchscreen interface and is more concentrated on the users' experience of typing and the relevance of the size of the objects for the general experience. The interview also gives the participants a chance to suggest future improvements of the technology. The final question is about what would be the ideal interface for the participants to have on their own personal computers.

4.2.1 Touchscreen interface

As already mentioned, only results regarding touchscreen related questions are presented here and grouped in the following five categories: general negative aspects, general positive aspects, typing – positive and negative aspects, suggestions for improvement, difference in using touch with bigger objects and smaller objects

4.2.1.1 General negative aspects

In general there were more negative than positive aspects that the users saw with touchscreen interface compared to the traditional interface. The participants revealed a number of things that irritated them. These topics are grouped together in major themes. All mentioned problems about typing with touchscreen are placed in a separated section (see section 4.2.1.3). The following themes emerged here were:

- ***Screen problems*** – there is too much friction with the screen surface. The screen sensitivity varies a lot sometimes one presses hard but nothing happens while other time there is unintended touch that causes problems. The screen also causes annoying reflection.

- ***Selection related problems*** – the interface requires too much precision when tapping for selecting smaller objects and the error rate feels high. Example of such selection problem is the resizing of a window (see figure 9 in section 4.1.3).
- ***Gesture related problems*** – some gestures are hard to be made or the computer does not always recognize them, for example when tapping with two fingers for doing right click.
- ***Individual aspects*** (mentioned by only one single participant) – one of the participants mentions that the arm blocks the view of the screen. There is also complaint that the touchscreen interface was physically tiring.

4.2.1.2 General Positive aspects

Despite finding more negative aspects with touchscreen than positive aspects, the things that the users liked with touchscreen are also interesting. It is important to mention that one of the participants did not find any positive aspects with touchscreen.

- ***Direct control*** – the interaction with the PC is more direct when using the touchscreen than with keyboard and mouse. There is no need for intermediary tools and the users feel like they can control the objects directly with their bodies.
- ***Photo management*** – the experience of sliding the photos and zooming in and out in a particular area of the photo was very appreciated by the users.
- ***Fun*** – it feels fun using the touchscreen PC.
- ***Scrolling*** – to scroll around in documents and webpages is particularly easy and fast.
- ***Individual aspects*** *(other positive things)* – having the interacting interface right on the touchscreen can save space on the desk, that otherwise is taken by the mouse and keyboard. The touchscreen interface can be faster for some task, but none particular example was mentioned by the users. The possibility to have bi-manual usage gives advantage to touchscreen compared to the mouse.

4.2.1.3 Typing – positive and negative aspects

Since one of the fundamental ideas behind the traditional keyboard is typing, then it is particularly important to understand how the users experience the typing process with touchscreen. Both positive and negative aspects are taken into account. Two of the participants couldn’t think of anything particularly positive with the touchscreen typing. From the rest emerged the following:

Positive aspects

- ***Flexibility*** – it is more flexible than the traditional interface, because one can configure the virtual keyboard in many ways, for example to change the size and the language (alphabet symbols).
- ***Individual aspects*** – To be able to type directly on the screen instead of just watching the screen. Typing on the screen can feel nicer for the senses, primarily for the ears (no irritating sound from button pressing) and for the touch since the screen is so flat and smooth.

Negative aspects

- ***Not comfortable*** – to type on the touchscreen for longer period does not feel so comfortable both for the body position and the physical fatigue. Even the screen angle is not perceived to be optimal.
- ***Slow*** – the process of typing with the virtual keyboard is experienced as rather slow in comparison to traditional physical keyboard.
- ***Unusual feeling*** – the feeling of typing in the screen is different than the feeling of typing with the physical keyboard. The users described it as weird feeling, because the sounds made when striking the keys and the screen surface material are different than those of the traditional keyboard.
- ***Individual aspects*** – making unintended touch with either the hands or even the clothes is irritating. It feels like one makes more errors when one types on the touchscreen than with the traditional keyboard. The virtual keyboard takes some space of the screen that can block some useful information.

4.2.1.4 Comparing the two touchscreen modes

Since the size of the objects is one of the foundations this study is based on, then even in the interview part it is important to know how the users experience the touchscreen interface when the objects on the screen are smaller or bigger. In this section only data related to the comparison of the two touchscreen modes is presented. In general the participants did not have a lot to say but they agreed on the following:

- ***Easier with bigger objects*** – All of the participants thinks that manipulating bigger objects feels easer when doing the tasks. For example to move objects like icons or a window.
- ***Less error making with bigger objects*** – It feels like one makes less errors when dealing with bigger objects than when dealing with smaller objects.
- ***Individual aspects*** – To have smaller objects feels like one can have better overview of all objects on the screen.

4.2.1.5 Participants suggestions for improvement

The results in this section are used to stress even more the problem areas with the touch interface. It gives also possibility for the users to express their wishes and thoughts for future development of the touchscreen technology. No particular individual aspects emerged this time since the participants had similar answers with no individual exceptions. The following themes emerged:

- ***Better angle and surface*** – the adjustability of the monitor's angle could be improved to allow even lower than 30^{o} counting from horizontal. Also the screen surface should not cause friction nor a disturbing amount of light reflection over the screen surface.
- ***Better and smarter screen sensitivity*** – unintended touches should not occur so often. The computer could also learn and adapt the sensitivity individually for each person.
- ***Better multi-touch and bi-manual usage*** – the involvement of more than just two fingers at a time and more involvement of both hands.
- ***More visual indicators and information*** – the indicators and the information in Windows are based on the traditional interface and performing the same actions with finger tapping and gestures does not work so well. Visual indicators adapted to the touchscreen are needed so that one can select objects with higher precision.
- ***Design for finger precision*** – some tasks require too much precision. The software should be designed for the level of precision needed for the fingers and not for the mouse arrow only. The computer could also adapt to the precision level of each user.
- ***Better virtual keyboard*** – the virtual keyboard could adapt to the screen instead of being fixed, depending on the task that is performed. It should be easier to call the virtual keyboard every time is needed.

4.2.2 Traditional interface

Only the results regarding the traditional interface are presented here. Only questions about general positive and negative aspects were asked to the participants. Since the traditional interface is not the main interface mode to be analyzed in this study, no deeper information is required regarding this system, which means that neither improvement suggestions related topics nor typing related questions were asked. In general, more positive than negative things were mentioned about the traditional interface.

4.2.2.1 Negative Aspects

One of the participants did not say anything negative about the traditional interface. Regarding the rest of the participants, the topics mentioned were:

- ***Too many tools on the desk*** – the mouse and the keyboard are taking a lot of desk space and it feels like there are too many tools around.

- ***No direct interaction with the objects*** – one cannot interact directly with the objects on the screen but has to use intermediaries (the keyboard and the mouse).
- ***Individual aspects*** – it feels too passive, too little movement. To type on the keyboard can sometimes take away the attention from the screen. Even the traditional interface can cause physical stress if used constantly for a long period of time.

4.2.2.2 Positive aspects

- ***High precision*** – the mouse arrow feels more precise than the fingertip, especially for selecting smaller objects. For example it is easier to resize the window border. One can also adjust the mouse cursor (size, speed, and look).
- ***Fewer errors*** – in general the error rate feels lower with the traditional interface than with the touchscreen.
- ***Faster*** – to perform the tasks went faster with the traditional interface. The keyboard with its shortcuts makes it faster in general and especially when typing. The right click with the mouse is also faster.
- ***A well-known and familiar interface*** – the traditional interface is established for some decades now and is already learned, while the touchscreen interface is new for the users. It is taken for granted to have and use the traditional keyboard-mouse interface.
- ***Individual aspects*** – the traditional interface cause less stress for the arms. It gives better view on screen, the arms and the fingers are not in the way blocking the screen.

4.2.3 Interface rating

The participants were asked to rate their experience using the two interfaces. They had to give marks between 1 and 5 for each of the interfaces, where 1 stands for worst experience and 5 stands for best experience. An average value for all grades is made for each interface. The following emerged:

- The average mark for the touchscreen interface is **2.7** – that means that general experience of the participants regarding the touch interface is neither so bad nor so good.
- The average mark for the traditional interface is **4.3** – that value indicates that the users' experience of the traditional interface was not perfect but very good.

4.2.4 Ideal PC configuration

Because today the touchscreen technology is available in the PC market, then there are three PC configurations a regular user can choose from: PC with touchscreen interface only, PC with traditional keyboard-mouse interface only, or a hybrid PC with both touchscreen and traditional interface. After using the touchscreen technology on a PC for the first time it is interesting to find out which of the three PC configurations the participants would like to have/on their own computers. Since this essay is considering only technical issues of the problem, then the participants were told to answer that question without thinking of the eventual price that their ideal personal computer would have

Without the money factor, all six participants chose to have a combination of both interfaces as their preferred PC configuration. This result is particularly interesting for a later discussion, when taking into account their general attitude of not liking the touchscreen interface that much. Even the participant, who did not find anything particularly positive with the touchscreen interface after completing the tasks, chose to have a computer with both interfaces. The explanations for why they chose to have a hybrid computer can be summarized as follows:

- ***It is the future*** – because touch interface will become more popular among PCs.
- ***Two ways of interaction*** – having two different options for interacting with the computer might be useful in certain occasions.

5 DISCUSSIONS

Touchscreen is an interface mode that offers many possibilities for letting people interact with the computer in a more natural and simpler way. Nevertheless, traditional interface based on the usage of a physical keyboard and mouse continues to be faster and shows a lower error rate than touchscreen interface. When analyzing the previous experiments conducted by Sears in the late eighties and beginning of the nineties (section 2.3.1) it becomes clear that, in many ways, touchscreen interface is still facing a lot of the same difficulties that it did roughly 20 years ago. There are several similarities between the experiment performed for this essay and those performed by Sears. His experiment concerning selection-related tasks using both traditional mouse and touchscreen interface (1989) shows that, although traditional mouse tended to be in average faster than touchscreen, this last interface was actually even faster than mouse when selecting big objects (between 32 and 16 pixels across). On the other hand, the time needed for selecting an object became considerably longer when using touchscreen interface as the objects to be selected got smaller, being the mouse, in this case, significantly more effective to rapidly select those small objects. Likewise, the experiment performed for this essay also shows that traditional mouse is clearly more efficient than touchscreen interface in most of the tasks that involve selecting objects, in particular smaller objects of just a few pixels across (less than one centimeter). Nonetheless, and just like in Sears' experiments, in task 3-d, which involved selecting and deleting icons, which are almost two centimeters across, traditional mouse was in fact approximately 13% slower than touchscreen interface running at the same resolution. This shows that, when selecting bigger objects (not smaller than one centimeter), touchscreen interface can actually be even faster and more effective than traditional interface.

In relation to gesture-based actions, the results in favor of traditional mouse were, also here, more recurrent than those for touchscreen interface, although in this case it is not possible to compare with Sears' results since his research analyzed selection-based actions only. For example, in tasks 5-b, 5-c and 5-d, which involved photo manipulation, traditional mouse kept its tendency to be the fastest interface, but one must not forget that these actions, when performed with mouse, are still selection-based actions. Touchscreen interface, on the other hand, lets the participants to perform these tasks by using gestures. In task 5-c, that required the participants to rotate a photograph, one can observe that both, the time needed to execute the task and the error rate, was actually longer when using traditional mouse in comparison with touchscreen interface running at the same resolution level.

Finally, regarding typing-related tasks, Sears' experiment comparing traditional physical keyboard with a touchscreen keyboard (1991) also gives results that show that physical keyboard is significantly faster than touchscreen interface. That same experiment suggests that, when using physical keyboard, it took the participants less than half the time needed when using touchscreen keyboard for writing the given text. In other words, normal keyboard was 132% faster than touchscreen. In a similar way, the experiment performed for this essay regarding a purely typing-related task (task 2-a) shows that typing on a physical keyboard was approximately 80% faster than doing the same task in a touchscreen keyboard.

The experiments conducted by Sears, regardless being done about 20 years ago, show in fact significant similarities to the experiments performed in this essay. Touchscreen technology seems to still lack a more precise way for making successful selections at the first attempt and allowing faster and more error-free typing and selection, which in turn would imply a shorter time needed for getting the job done. Touchscreen interface is still not fully adapted to the precision level required by the finger touch.

In the same line of thoughts and regarding the interview results, it becomes clear that people still show some resistance to the idea of interacting with personal computers through touchscreen interface. Another evidence of that is the fact that the users in this study mentioned very little about the advantages that bi-manual usage, multi-touch and gestures in general can have for the interaction between a human and a computer. Many authors like Saffer (2009), Brolin (2006), Klemmer, Hartmann and Takayama (2006) have pointed out the importance of these elements when one wants to develop a better interactive computer system. And yet it seems like the manufacturers of touchscreen personal computers and software developers have not fully understood the great potential that touchscreen interface can offer for this type of machines.

Touchscreen technology for personal computers must also be improved in terms of the surface sensor area of the touchscreen which the participants found problematic. Things like level of sensitivity, unintended touches, friction level and excessive reflection on the screen are just a few of many problems that still must be addressed for making a better touchscreen experience with a PC.

The ergonomic problems like discomfort and fatigue mentioned by Shin and Zhu (2011) are present mostly during typing on the touchscreen. Even the angle of 30^o suggested by Sears for the monitor position was still not perceived by the users as the optimal.

Very interesting in this matter is the fact that the participants did not mention directly that the touchscreen interface feels more natural than the traditional interface and, to some extent, almost quite the opposite. One explanation for this could be that the traditional interface has been used by people for much longer time and therefore both software and hardware has been designed having traditional interface in mind, while the touchscreen is still a rather new interface for the general public and even for developers.

Finally, interesting to discuss is the fact that although the participants rated the touch interface giving it a grade almost half the one given to traditional interface, they still preferred the idea of having a personal computer that combines both interfaces rather than having a computer that offers only traditional interface. Probably somehow the users are aware of the potential that touchscreen has for PCs and after seeing the big impact that this technology has had for handheld devices like smartphones and tablets, then the next logical step might very well be to have this interface in personal computers as well. The possibilities that touchscreen-based gestures offers for executing different types of actions rapidly and intuitively might, at least in part, replace traditional keyboard and mouse for executing some particular actions on the near future.

6. CONCLUSIONS

Touchscreen technology for personal computers offers many new possibilities of interaction with these machines and yet the industry is still somewhat doubtful to start manufacturing every new personal computer with a touchscreen interface. The experiment conducted in this study in combination with the interviews done with the participants of this study show that touchscreen interface, compared with the traditional physical keyboard and mouse, is still slower for performing almost all sorts of tasks, with only a few exceptions. A personal computer is, perhaps unlike any other device, a multitask machine that allows people to use a wide, almost unlimited, variety of applications covering different activity areas. These areas, although being many, can be categorized into two main groups: productivity activities and recreational activities. The experiment performed suggests that recreational activities, such as casual web browsing or photo viewing, work remarkably well with touchscreen. Not only did this interface prove to be easy to use and fairly intuitive, but also it allowed the users to directly interact with objects like photos and files in a much more direct way, without the need for using any other tool but their own hands. This aspect was something appreciated by the users because it makes the interaction feels more natural and even more fun. When it concerns productivity-related activities, however, there is one single factor that plays the decisive role when determining the effectiveness of a certain interface system: time. This implies that touchscreen, among personal computers, is in a clear disadvantage in comparison with the traditional interface when it comes to productivity-related activities. Typing becomes here a critical factor since this type of activities involves plenty of data entry. Ergonomical aspects are also of extreme relevance for productivity-related activities, not only due to the fact that a comfortable working position improves speed, but also given the long periods working with the computer during a whole working day. As mentioned by many of the participants during the interviews, typing on a touchscreen keyboard was experienced as a relatively tiring activity (even if the text they wrote was roughly three lines long). Similarly, the execution of certain type of tasks, many of them regarded as trivial when using traditional keyboard and mouse, resulted to be quite a challenge when using touchscreen interface, for example, when resizing a window or other similar type of task that required the user to select a fairly small object on screen.

The technical reasons of what makes touchscreen interface for personal computers to be slower than traditional interface and to have a higher error rate are, as observed during the analysis and the discussion, numerous and of vary diverse nature, ranging from software related issue to hardware problem. Nevertheless, there are two main aspect that might explain in a very concrete way the somewhat weak penetration that touchscreen interface has had among personal computers. Firstly, the operative systems and software in general written for these type of computers has been designed almost uniquely for the usage of traditional keyboard and mouse and not for touchscreen interface. This implies that even if there are several personal computers with touchscreen capabilities in the market, the software they are running does not perform in the most effective way when using the fingers for selecting an object, instead of using a regular mouse. Secondly, personal computers have been around for roughly thirty years, which means that many users have been using physical keyboard and mouse as their main interface systems for many years, perhaps decades. Changing paradigms is a slow and long process and, unlike other newly come devices like smart phones and tablets, where touchscreen has already become the mayor trend, it will probably take some time to make the general public understand that there are many other ways for interacting with a personal computer than just physical keyboard and mouse.

7. SUGGESTIONS FOR POSSIBLE INTERFACE IMPROVEMENTS

After analyzing all the data obtained during both the observational experiment and the interviews, in combination with the analysis of the previous researches mentioned in this study, it is possible to suggest some areas of improvements that could be taken into consideration by software developers and hardware manufacturers. These suggestions are, however, of a very general character and fairly simple in technical aspects and by no means are intended to be a complete solution for the many aspects that can be improved within touchscreen interface, but rather a sort of guideline to be taken into consideration for future research and development. These suggestions cover four main areas mentioned below:

The material used in the touchscreen surface: When using touchscreen interface it is essential to be able to slide and drag the fingers over the screen surface smoothly and seamlessly. That is why the material used in the manufacture of the touchscreen surface plays a crucial role to ensure that the users will be able to perform the gestures with their hands over the screen without any difficulty. Some plastic materials used in some screens make their surfaces to give too much friction, which does not only make the experience of swiping with the fingers rather uncomfortable, but also it can increase both time and error rate. A special treated glass or plastic material that offers the least possible friction to ensure a smooth finger slide is essential for touchscreen interface.

Easier to adjust the monitor's angle: When using touchscreen interface on a personal computer, being able to easily and effortless adjust the monitor's angle is something of extreme importance to ensure that the experience of using the computer will be pleasurable ergonomically speaking. Physical stress and fatigue in hands, arms and even shoulders can occur as a result of an inadequate working position. Different types of tasks might require different monitor's angle. For example, when just surfing the Internet or viewing pictures the users tended to position the monitor in an angle of about 75 degrees (counting from horizontal), while when typing text on the virtual keyboard a common angle for the monitor was around 30 degrees. Personal computers with touchscreen must, therefore, have a mechanical system that allows the user to easily adjust the monitor's angle at any time.

Bigger objects on screen to suit the precision level of the finger: This aspect has a tremendous repercussion in how effectively touchscreen interface will work on a personal computer and it is mainly related to the concept of Fitts' law and the size of the finger as a selecting element. Both the previous research as well as the experiment conducted for this study suggest that the effectiveness of touchscreen interface when selecting objects on screen decreases dramatically as the objects become smaller. For a software to be touchscreen friendly it is required that the whole graphical structure in terms of objects' size must be designed having in mind the fact that, unlike the traditional mouse arrow, the human finger is much cruder selecting element due to its size and shape.

More bi-manual, multi-touch and gesture-based usage: The usage of both hands simultaneously for operating with the touchscreen could allow for a whole new level of interaction, for example one could move two objects at the same time, which would speed up some tasks and increase the level of productivity. To use more than two fingers at the same time to perform actions and in combination with bi-manual interaction would increase the level of control and the whole experience could feel even more similar to the way we handle objects in the real world. More gestures and multi-touch options, for example, making a gesture with four fingers gives possibility to execute ever more sophisticated tasks. Also, the usage of sequential gestures (where one performs the actions in a sequence of gestures to complete the task), for example, drawing an "X" with the finger over the screen to close a program. In addition, the possibility to create own gesture allows the people to personalize and adapt the interaction for individual needs. The technology to do all this exists already, but so far few computers make real use of this technology.

8. FUTURE RESEARCH

Due to limitations regarding time and resources the experiment performed in this essay involved the participation of a fairly limited number of volunteers. A study with more participants is essential for getting a deeper insight about how people interact with a computer by using touchscreen–based interface and for being able to identify other possible trends. It is necessary to do further research concerning the attitude that the general public has towards this new interface mode in order to be able to elucidate exactly which are the most problematic issues that must be addressed so that this interface will become truly effective.

The main problems regarding this interface discussed in this experiment were based on the results of an observation made using one single computer model. It is, therefore, important to make further experiments using other models since the evolution of this interface goes at a tremendous rate and introduction of new technologies takes place constantly.

Another opportunity for future research using the same approach would be to change the nature of the tasks that are to be executed by the participants. The tasks that the participants had to execute in this research were rather basic in terms of difficulty level. Testing touchscreen interface with different and more difficult tasks might show some different results.

9. REFERENCE LIST

9.1 Books and articles

Andersson, M., Bäck H. (2009) *An adaptable application structure for multi-touch screens,* Bachelor Thesis 30 ECTS ,School of economy, communication and IT, at Karlstad's University, Karlstad, Sweden.

Bell, J. (2006) *Introduktion till forskningsmetodik*, 4th edition, Studentlitteratur AB, Lund, Sweden.

Benko, H., Wilson, A. D. , Baudisch, P. (2006). *Precise Selection Techniques for Multi-Touch Screens*,CHI '06: Proceedings of the SIGCHI conference on Human Factors in computing systems. ACM. New York, NY, USA.

Brolin N. (2007) *Gesture recognition for Touchscreen Interfaces using Simultaneous Multiple Inputs*, Bachelor Thesis of Science degree in Games Programming (GP) 180 ETCS, Luleå University of Technology, Campus Skellefteå, Sweden.

Dourish, P.(1999) *Embodied Interaction: Exploring the Foundations of a New Approach to HCI*. Volume: HCI in the, Issue: HCI in the New Millennium, Xerox Palo Alto Research Center, CA, USA.

Klemmer S. R., Hartmann B., Takayama L. (2006) *How bodies matter: five themes for interaction design*, Proceedings of the 6th conference on Designing Interactive systems, June 26-28, 2006, University Park, PA, USA.

Saffer, D. (2009) *Designing Gestural Interfaces*, 1st edition, O'Reilly Inc., Sebastopol, Canada.

Scali, F. (2010) *Webbgänssnitt på pekskärmsdatorer - En användarstudie av webbplatser på Ipad*, Bachelor's thesis 15 ECTS, School of Communication, Media and IT, at Södertörn University, Stockholm, Sweden.

Sears A., Shneiderman B. (1989) *High Precision Touchscreens: Design Strategies and Comparisons with a Mouse*, International Journal of Man-Machine Studies 1991, volume 34, pages 593-613, MD, USA.

Sears A. (1991) *Improving Touchscreen Keyboards: Design issues and a comparison with other devices*, journal: Computers, volume 3, pages 253-269, MD, USA.

Shin G., Zhu X. (2011) *Ergonomic issues associated with the use of touchscreen desktop PC,* Proceedings of the Human Factors and Ergonomics Society Annual Meeting September 2011 vol. 55 no. 1, pages 949-953.

9.2 Electronic sources

Documents

Namahn (2000) *Touch screens – the ergonomics: a Namahn brief*, Available at <http://www.namahn.com/resources/documents/note-Touchscreens.pdf>. Retrieved 18.11.2011

Forum sites

The Top Tens www.the-top-tens.com, *Best Computer Brands*, voting forum by user: **dragon13304**, available at <http://www.the-top-tens.com/lists/best-computer-brands.asp> Retrieved 12.11.2011

Computer manufacturer sites

HP, US webpage, available at <http://www8.hp.com/us/en/home.html> Retrieved 12.11.2011

Acer, US webpage, available at <http://us.acer.com/ac/en/US/content/home> Retrieved 12.11.2011

DELL, International webpage, available at <http://www.dell.com/> Retrieved 13.11.2011

APPLE, International webpage, available at <www.apple.com> Retrieved 12.11.2011

LENOVO, US webpage, available at <www.lenovo.com/us/en/#ss> Retrieved 12.11.2011

ASUS, International webpage, available at < http://www.asus.com/> Retrieved 12.11.2011

SONY, International webpage, available at <http://www.sony.net/> Retrieved 12.11.2011

Toshiba, US webpage, available at <http://www.toshiba.com/tai/> Retrieved 12.11.2011

Pictures

Figure 5
picure a), available at
<http://h10025.www1.hp.com/ewfrf-JAVA/Doc/images/c02705087.jpg> Retrieved 12.12.2011

picture b), available at

<http://cdn.zath.co.uk/wp-content/uploads/2011/02/TouchSmart_270x334-242x299.jpg>

Retrieved 12.12.2011

9. Appendix

Observation – task list

List of tasks

1. Windows management

a. Open a window and then move it a whole circle around the screen

b. Minimize the window, restore it, maximize it and then restore it again.

c. Resize the window: make it larger by clicking on the corner and drag it until it reaches the clock in the task bar; lift finger and then resize again to the smallest possible size and then close it.

2. Typing

a. Adjust the monitor angle to best suit your preferences. You can also resize the keyboard to the desired scale. Type the text beneath:

> " I am typing this text as part of an observational experiment within Medieteknik C and I am having the time of my life.
>
> I wish you guys good luck in your research. "

b. Select the text, copy it and paste it beneath the text you already wrote
c. Save the text in the computer desktop and close Word

3. File management

a. Create a folder on the desktop and name it "test1"

b. Open the folder and create a subfolder and name it "test2"

c. Drag the document file you previously created into the "test2" open "test2" and drag the text file back to the desktop.

d. Delete the folder "test1" and the text file in the desktop.

4. Web browsing

a. Go to *htc.com then c*lick on “smartphone” in the site’s upper menu

b. Scroll down until the third phone. Turn the phone facing backwards by dragging it. Go back to the start page (medieteknik och information)

5. Photo management

a. Click on the icon right beside the start button, open the folder “pictures” in the left sidebar, now open the folder “sample pictures”, double click in the “penguins” picture.

b. Slide among all the pictures until you end up in the penguins photo again

c. Zoom in and out twice.

d. Rotate the photo until the penguins are upside down and then rotate it in the opposite direction so that the photo is in the original position again.

Interview – questionairre

Interview

Comparison between touchscreen interface and traditional keyboard-mouse interface

1. Grade your experience as a whole using the HP touchscreen interface. The scale being 1 for worst mark and 5 for best mark.
2. Grade your experience as a whole with the traditional interface using this computer. Same 1 to 5 scale.
3. Name the positive aspects you find about touchscreen interface with this computer.
4. Name the negative aspects you find about touchscreen interface with this computer.
5. Name the positive aspects you find about the traditional interface using this computer.
6. Name the negative aspects you find about the traditional interface using this computer.

About Touchscreen only

6. Based on your experience with this computer, what do you think could be improved regarding touchscreen technology to make it a fully reliable and useful interface?

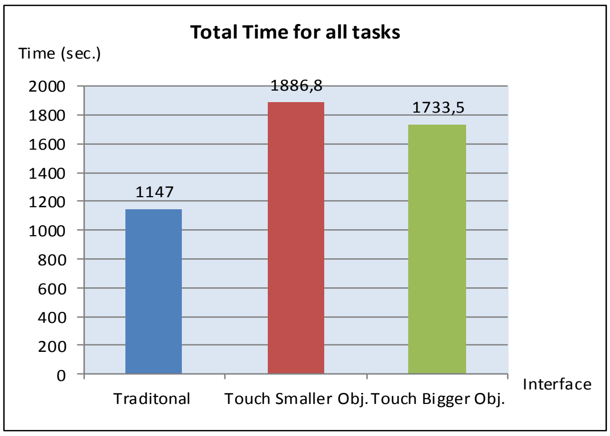
7. Name the main positive aspects of typing with a virtual keyboard on the screen.
8. Name the main negative aspects of typing with a virtual keyboard on the screen.
9. Did you experience any difference with the standard and the lower resolution? What?

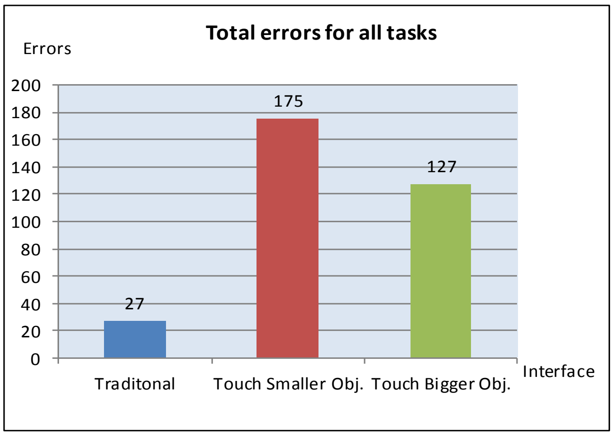
Touchscreen in personal computing

1. Based on your experience with this computer, which of the following alternatives would be your ideal personal computer?
    - Touchscreen interface only
    - Traditional keyboard-mouse interface only
    - A personal computer having both traditional and touchscreen interface.

Results – graphs

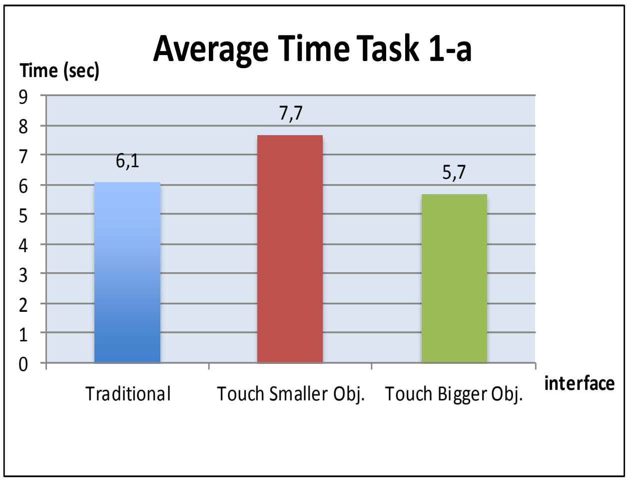
Total time and Error Rate for all tasks

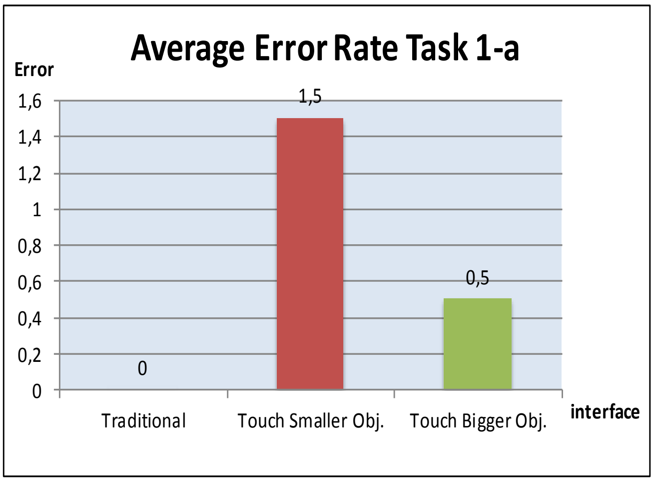




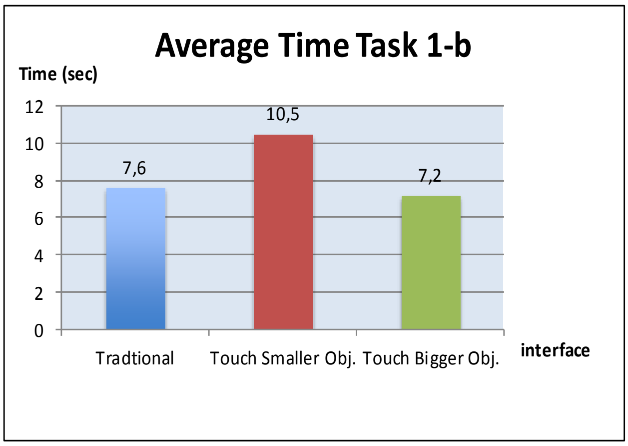
Average time and Error rate per task

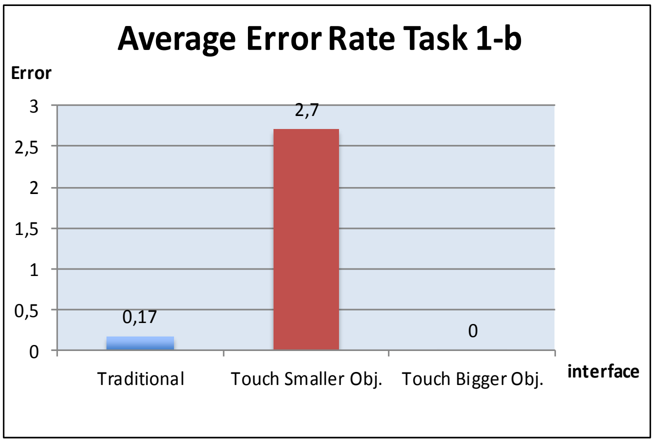
Task 1 a



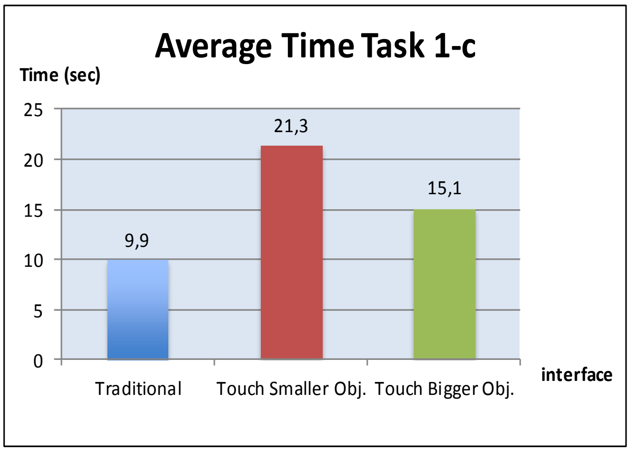


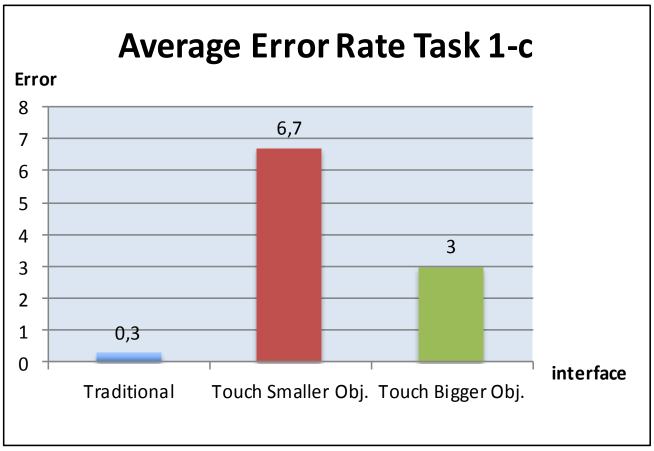
Task 1b



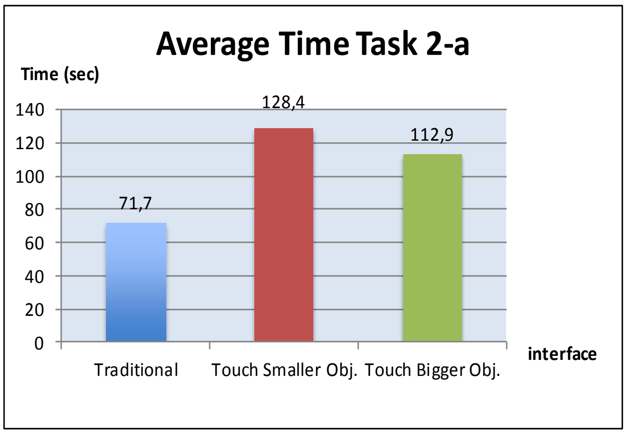


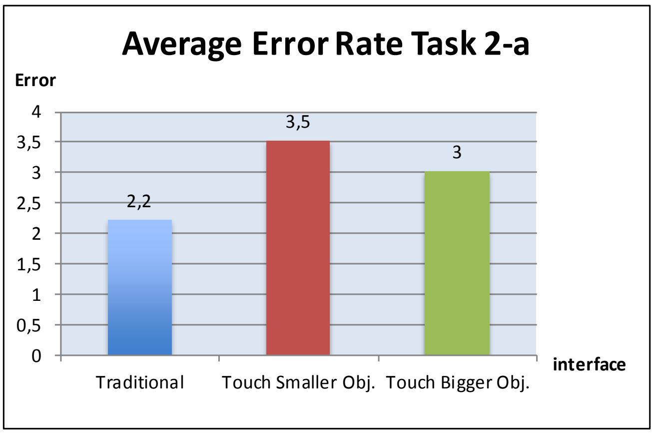
Task 1c



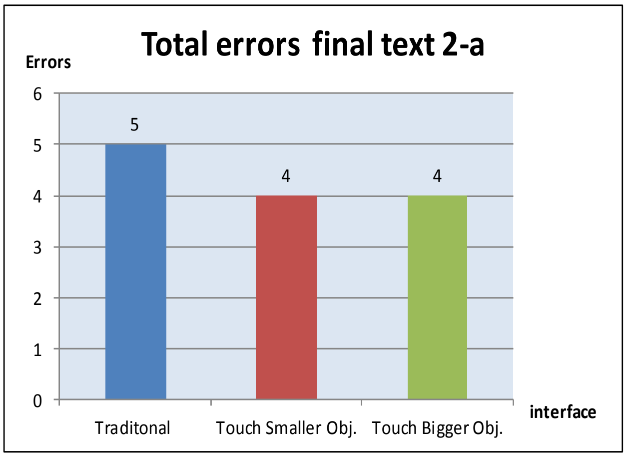


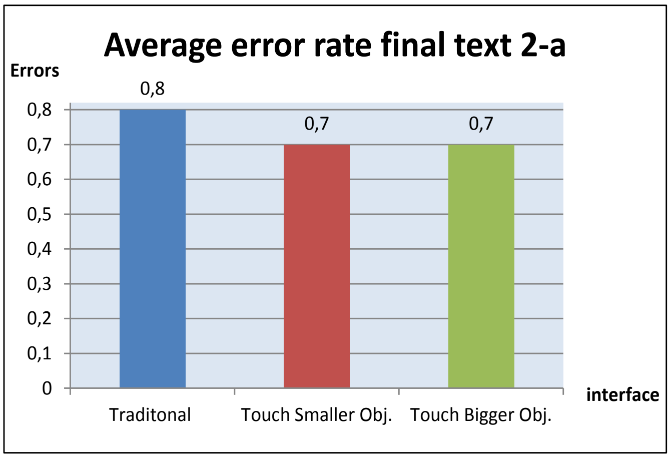
Task 2a



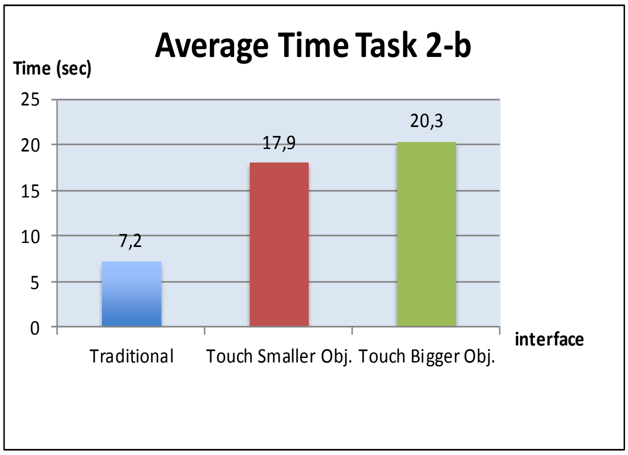


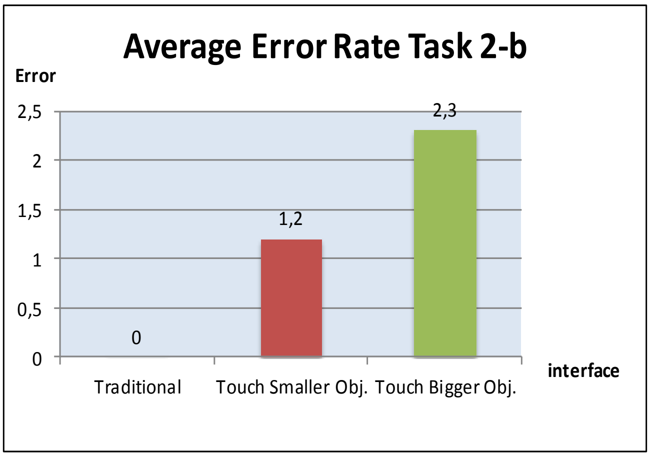
Task 2a final text only errors



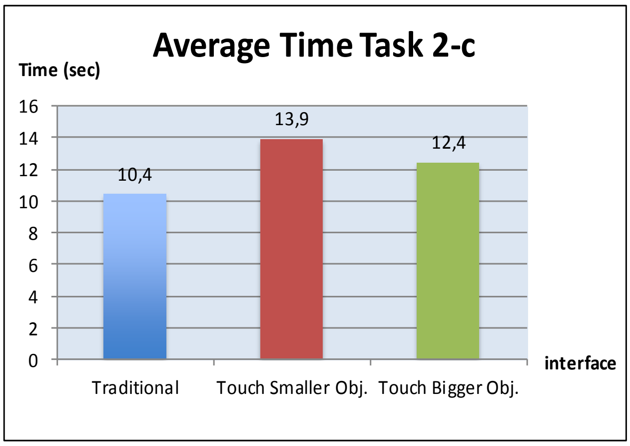


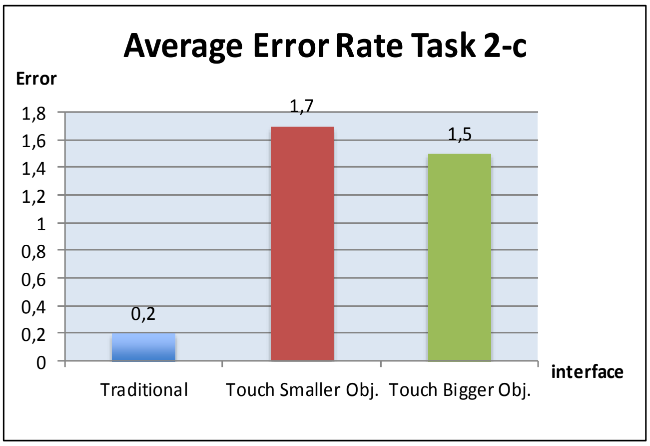
Task 2b



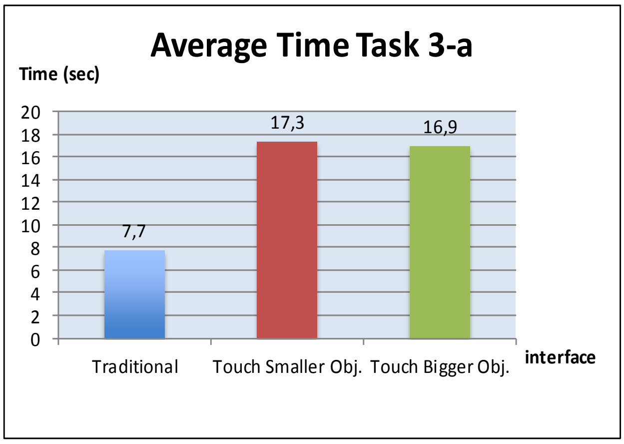


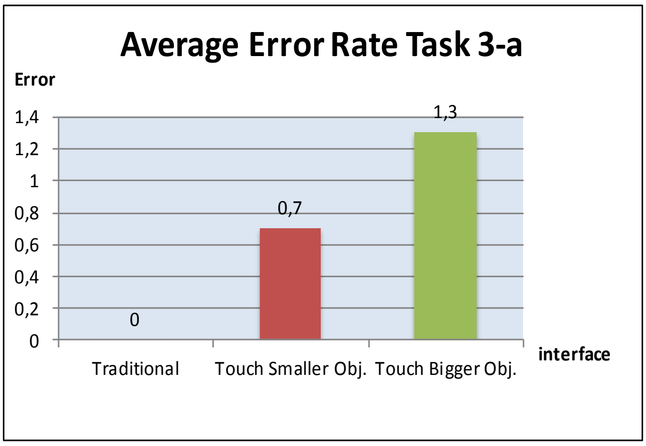
Task 2c



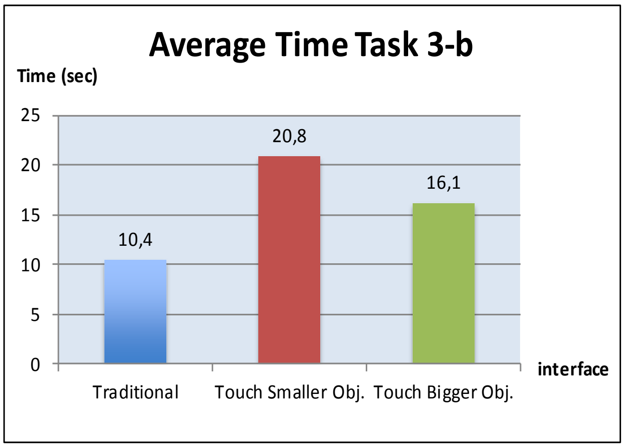


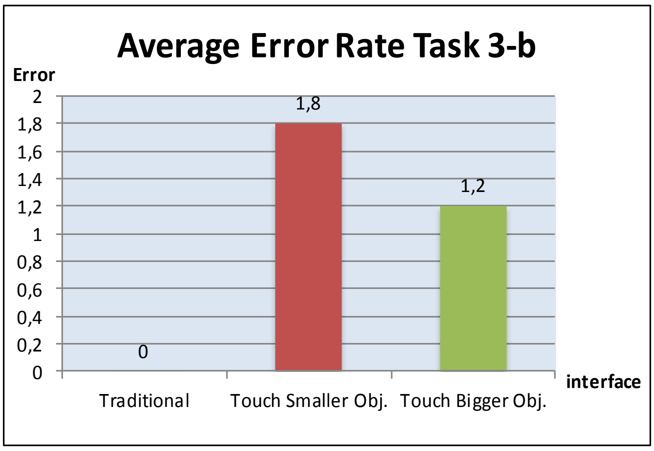
Task 3a



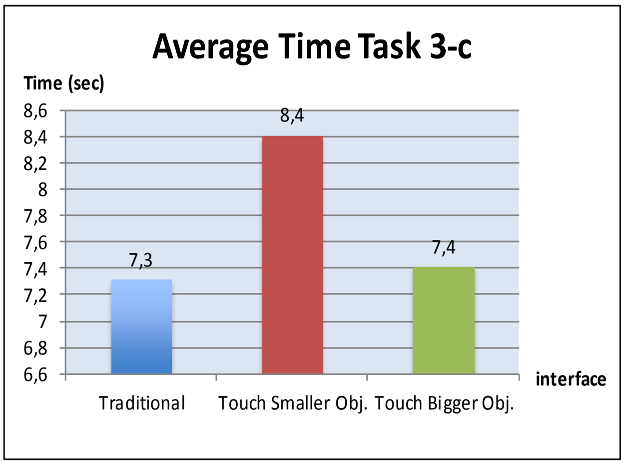


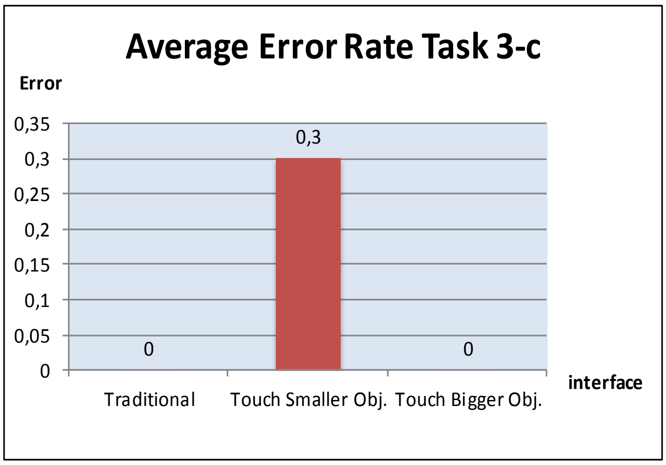
Task 3b



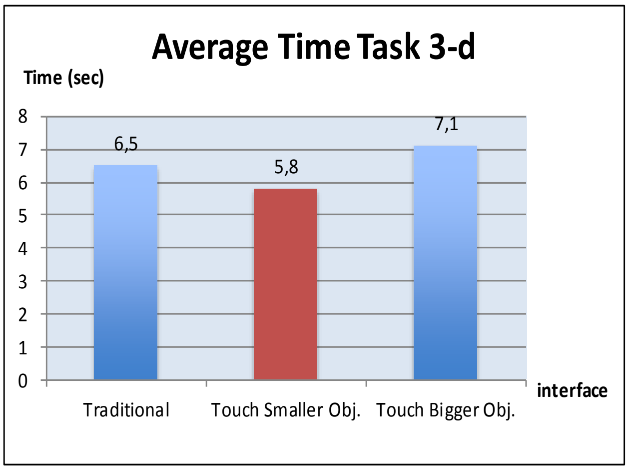


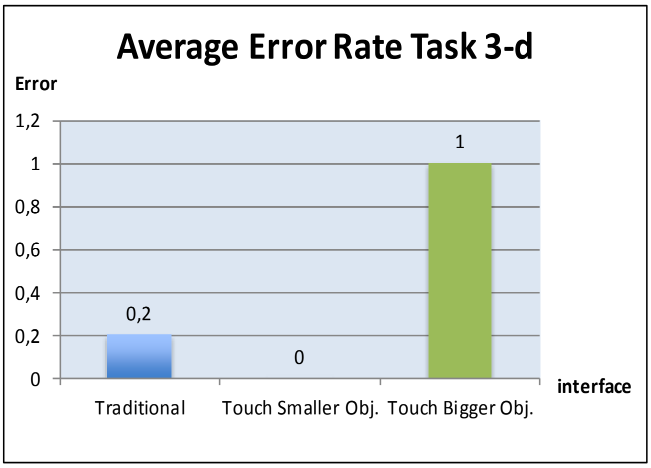
Task 3c



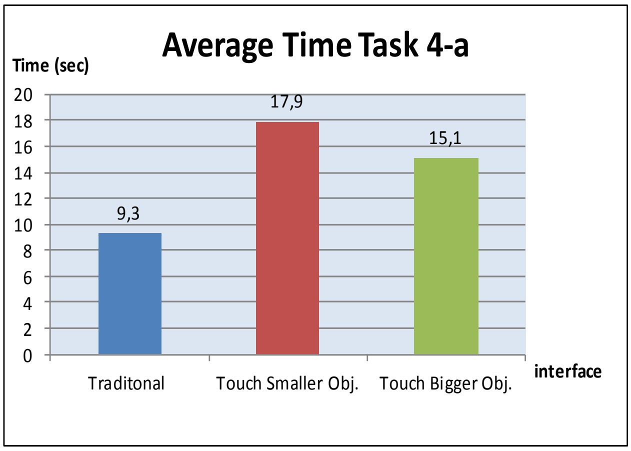


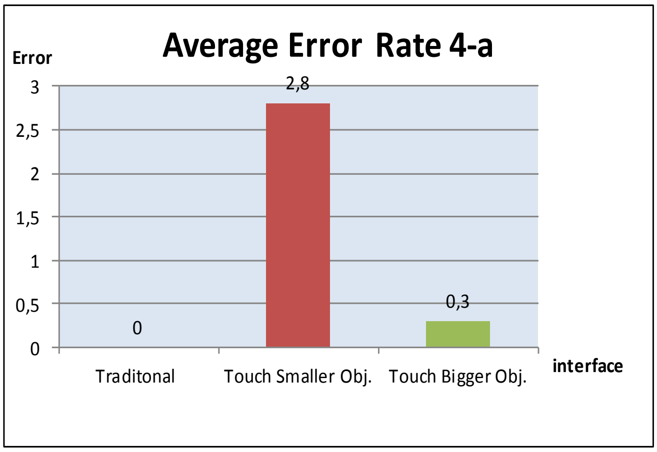
Task 3d



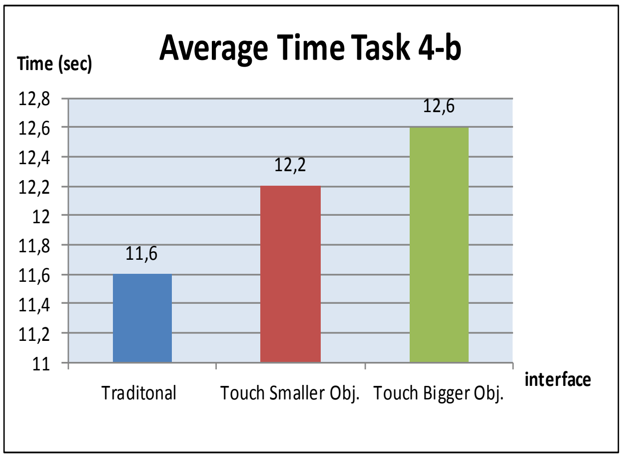


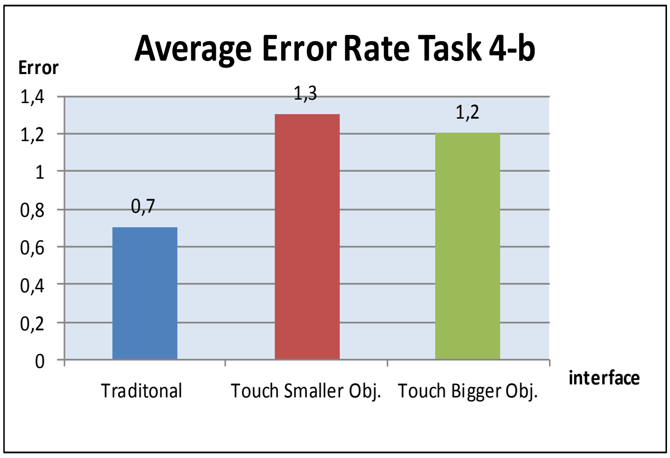
Task 4a



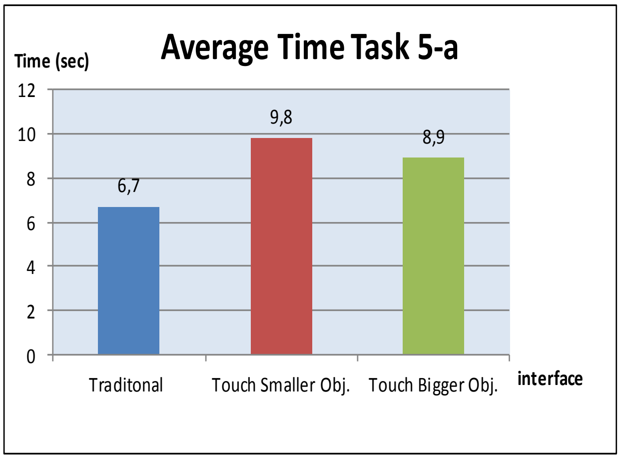


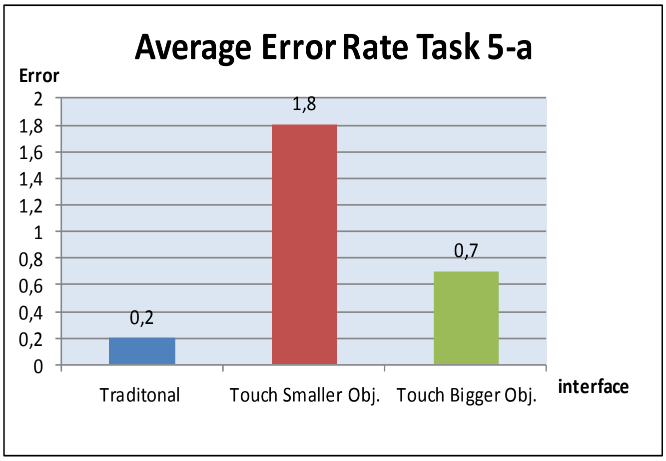
Task 4b



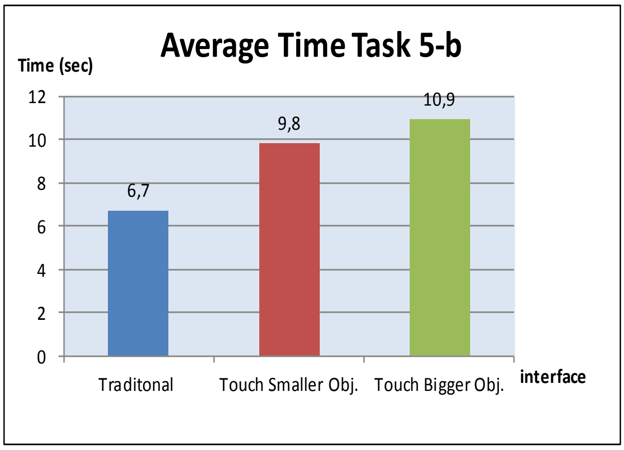


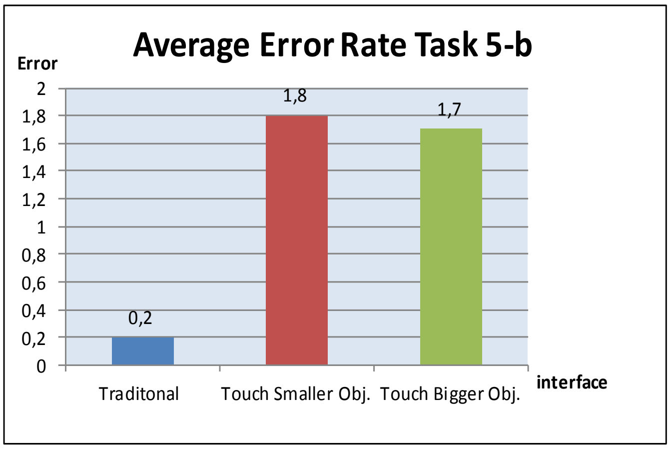
Task 5a



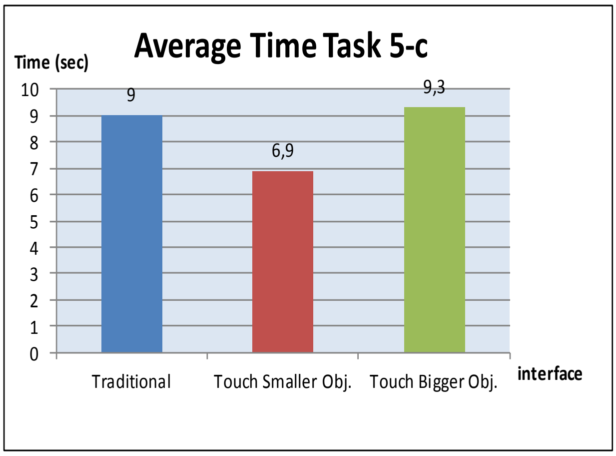


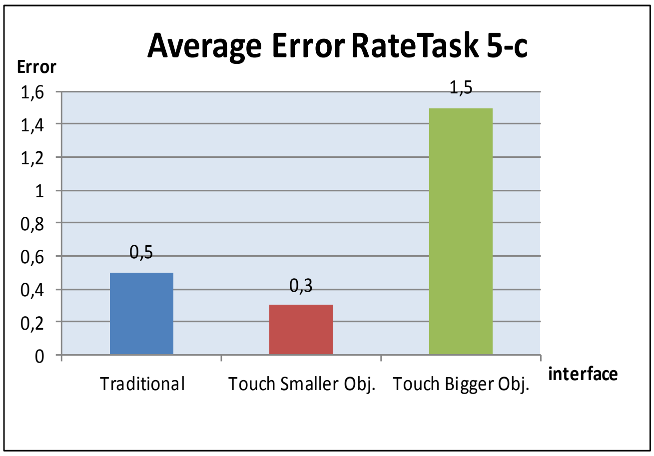
Task 5b





Task 5c





Task 5d