Interface Design and Evaluation for Tablet Devices with Different Screen Sizes

Fateme Rajabiyazdi

A subthesis submitted in partial fulfillment of the degree of
Master of Computer Science (Honours) at
The Department of Computer Science
Australian National University

June 2012

Typeset in Palatino by TeX and $\LaTeX\,2_{\varepsilon}$.

Except where otherwise indicated, this thesis is my own original work.

Fateme Rajabiyazdi
28 June 2012

To my husband and my family.

Acknowledgements

The author would like to express her appreciations to my supervisor, Prof. Tom Gedeon and all participants of the experiments, iHcc meeting group for their support and thank Dr. Duncan Stevenson and Dr Dingyun Zhu for their helpful comments.

Abstract

In general, Personal Digital Assistant (PDA) devices are utilized for the purpose of reading, typing and playing games and etc. However, PDAs small screens size are not often convenience for users when they use it for a long period. Small screens force us to use smaller fonts to fit a page or scroll over and over to read a page. A new device is implemented with a bigger screen size and a touchpad at the back of the display to overcome this problem. Experiment with two screen sizes have been conducted with the back trackpad in order to comparing the performance of using the device and the iPad through both objective measures and subjective measures.

Different users studies have been designed to examine the devices and run them on 56 participants. User studies include playing games, typing and navigating tasks. After experiment, participants answered a survey question about how much they feel comfort while they using the devices. The experimental results show that the 17 inch screen device and the iPad have no significant difference in playing games but the new device is significantly slower than the iPad in typing a paragraph. However, participants liked the device for playing games with that since the screen's device was quiet big and they enjoyed playing with that.

The 13 inch screen device was significantly faster in playing games than the iPad and there was no significant difference between them while users navigating. In addition, the 13 inch BackPad was more memorable than the iPad on maps.

The BackPad has an extra weight at the right side of the device because of the trackpad weight. Another experiment was designed to investigate whether this extra weight has any influence on the users' performance. A simulated 15 inch screen was examined on both right and left handed users and it was found that users' dominant hand strength was significantly higher than their non dominant hand while they holding a asymmetric weight device. Therefore, the extra weight will not affect on the users' performance.

Contents

Chapter 1

Literature Survey

Using mobile devices is becoming popular since people feel they need to have access to Internet everywhere and any time so they use a device to carry with them. A large number of mobile devices with various features have been introduced and manufactured for different purposes. Each of the mobile devices has some special features and advantages for itself, which leads users to buy them by their specific need. In spite of their advantages, they have some limitations such as small screen size [Bracken and Pettey 2007], hand cover [Vogel et al. 2009] and using them in noisy environment [Brewster 2002], which need to be fixed or redesigned.

In the section 1, some guidelines are given which are helpful for designing mobile devices depending on their functionality in addition to a comparison between mobile devices discussion. In the sections 2, 3, 4 and 5, mobile devices' functionalities such as reading, typing, playing games and navigation are investigated from various perspectives.

Depend on a mobile device's functionalities, the screen size has to be designed properly. Using a big screen for mobile devices makes them heavier and harder to carry; however, it increases the users' performance in some cases. In addition, using touch screen or non touch screen display for them is an important factor for designing mobile devices. The advantages and disadvantages of using big, small and touch screens will be discussed in sections 6 and 7.

For this project, we intend to design a new mobile device with new functionalities to cover part of the limitations in existing mobile devices. Using a bigger screen than the normal one in mobile device such as 10 inch or smaller and using a trackpad at the back of the screen to control the device rather than using a touch screen or a keyboard in front are the main new functionalities in our device [Rajabiyazdi and Gedeon 2012a]. Some previous in simulating a mobile device with a bigger screen is discussed in section 8.

In addition to designing new functionalities for a mobile device, it is important to consider ergonomic guidelines. Users' hand performance differs while they are completing different tasks on different devices [Rajabiyazdi and Gedeon 2012b]. Gripping or holding a mobile device is another factor which needs to be considered for designing, which is discussed in section 9.

1.1 Mobile devices

This section includes challenges that might occur in designing a user interface for a mobile device and some interface guidelines as well. In addition, it is important to consider mobile devices usage such in learning, typing, playing games and so on when the interface is designed from a customer perspective.

1.1.1 The Challenges for Designing User Interface

Designing a mobile device's user interface is always challenging. In 2002 five main Human Computer Interaction design challenges were introduced [Dunlop and Brewster 2002]:

- Designing for mobility: users usually use their mobile devices when they move or they are not in their work environment.
- Designing for a large number of people: many users do not have any skill to work with mobile devices.
- Designing for limited input/output facilities: devices are usually small due to portability and they have small keyboards. Users can not use pointing devices easily when they move.
- Planning for context information.
- Considering user multitasking.

Subsequently, in 2004 a number of new guidelines for designing mobile devices' interface have been added[Gong and Tarasewich 2004]: enable users to use shortcuts, which increase ease of device usage for frequent users, give users understandable and an informative feedback, design and organize sequences of actions and support Internal Locus of Control, which means the system has to be designed in a way that it gives users a sense of system administration.

In addition to considering the above guides, the system should be consistent, have error prevention, be stable for multiple and dynamics contexts, allow users to personalize their device and has to be designed for enjoyment.

Ten educational professionals who had experience in using hand-held technology were identified to participate in a study [Churchill and Hedberg 2008] to investigate the challenges of the small screen in the devices. An experiment was designed for a group of school students and four available hand-held devices were used during two lessons.

The study ended with some recommendations for the design of learning objects for delivery via hand-held devices. It has to be designed to support full screen presentation, landscape presentation, in addition to short contacts. The recommendations include minimized scrolling, one step interaction, zooming facilities, possible development of stylus pen interaction, and movable, collapsible, overlapping, semitransparent interactive panels. Therefore considering these recommendations and guidelines lead us to buy or even design a mobile device with higher performance and more functionalities.

1.1.2 Comparison Between Mobile Devices

Choice of mobile device depends on intended use. Each device is specially designed for a purpose. For examples, the eBook reader is designed for reading, Netbooks are mostly used for business purposes and the iPad is mostly used as an entertainment device. There are a number of devices designed mainly for business purposes or playing games or reading or and so on. Each one of these devices has advantages and disadvantages that have to be considered when users intend to buy them. This section compares mobile devices, iPad, Kindle and Netbook, their benefits and drawbacks as compared to each other.

Since reading eBooks from PDAs has become more popular, the advantages and disadvantages of using eBook has been discussed in a separate section, as it is worth investigating the challenges.

1.1.2.1 eBooks Readers

The eBook consists of three elements: content, eBook reader such as personal computers, Personal Digital Assistants (PDAs) and mobile phones, and reading software such as Acrobat reader [Han et al. 2010]. The eBook has some advantages and disadvantages [Yeh 2010]. Automatic search, portability, small size and big memory and less paper and ink usage are the most important benefits. For its drawbacks Yen mentions: electrical power need, difficult to read in bright sunlight, eye strains and not accepting historical book formats.

1.1.2.2 iPad, Kindle or Netbook

Deciding which mobile device to buy depends on our main usage and the device functionalities and disabilities. Kindle, iPad and Netbook from various range of mobile devices are chosen to discuss as the three most popular mobile devices these days.

Kindle (See Figure 1.1) is designed for reading books and can be used for educational purpose. However, its note taking does not work well and it only supports: black and white so it is not suitable for colour images or diagrams which are nominated as its drawbacks.

The iPad is a small, light and portable touch screen device with a long battery life. There are various ranges of applications such as games, weather forecast, note taking, web browsing and so on that iPad can handle. One of the iPad's advantages over the Kindle is the iPad supports a wide range of colours. In addition, the iPad can be used for other purposes than reading.

Figure 1.1: Kindle [web b]

A Netbook is a mini-laptop with low cost, low power system, low weight and small size [web d]. It is cheaper than an iPad, but does not have as many features as an iPad. However, it is useful for browsing or using Microsoft Office.

In summary, if you need applications offered by an iPad or multimedia nature of the device, then you should buy an iPad [Pratt 2010]. However, if you need a mobile device for only reading or browsing and using Microsoft office, a more cost effective purchase would be a Kindle or a Netbook.

Reading, taking notes, playing games and navigating on mobile devices are the most popular usages among them, which are discussed in the following sections. Considering mobile device functionalities to support these usages can lead us to buy a more convenient device.

1.2 Reading

Reading on mobile devices is becoming popular since users are busier and they prefer to read books, newspapers or magazines while they use public transportation or are on their way somewhere. This section will discuss this issue from different perspectives.

In [Waycott and Kukulska-Hulme 2003] study, students read course material with PDAs for two months. The course title was Application of Information Technology in Open and Distance Education. Some questions were asked before and after the experiments and an interview was conducted after the experiment. Students shared their experiences on a computer-base conference discussion with each other after they had finished the experiment period.

Participants mentioned some limitations such as small screen, more navigation between information and harder highlighting method than paper reading. Despite the limitations, they mentioned some benefits such as having access to the electronic format of their course material any time and anywhere [Waycott and Kukulska-Hulme

2003].

In addition, reading on the small screens obliges users to use smaller fonts in order to fit a page of their reading on the screen. A smaller font size due to low resolution and lighting conditions affects the reading process negatively [Kärkkäinen and Laarni 2002] and it decreases accuracy [Bergman 2000]. If readers choose larger fonts, they have fewer words per page and must scroll the screen up and down/left to right many times in order to read a page [Waycott and Kukulska-Hulme 2003].

1.3 Typing

Typing is a task that rarely is performed on PDAs [Nguyen and Chaparro 2010]. Many PDAs now have touch screens, which might be one of reasons typing is rarely performed as it is quiet difficult. The touch screen typing problems are discussed in this section in detail that may contribute to design a more comfortable mobile device for typing. Here, rear typing [Scott et al. 2010] is discussed as one for this problem solution.

In addition to the input used for typing, users' typing performance differs based on their skill. Studying novice and experienced typing performance can help PDA designers in terms of designing PDA's keyboards so it is worthwhile to study about it.

1.3.1 Users' typing performance

Typing speed on the small touch screen devices is slower than typing on larger devices [Sears et al. 1993]. Four keyboards with different sizes were examined in this experiment. The results showed that experienced participants typed approximately 21 words per minute on a small keyboard and 32 words per minute on a large keyboard. However, novice users were only able to type 10 words on small and 20 words on a large keyboard per minute.

Sears et al. also experimented with different keyboard sizes. The authors showed that novice and experienced subjects are slower at typing on small keyboards [Sears et al. 1993]. In addition, the authors have showed novice participants have fewer corrected typed errors with the large keyboard.

1.3.2 Touch screen typing

Typing phrases on touch screen devices has no feedback and it generally does not give any sense of touching the keys under fingers, which makes typing harder and slower than typing on a physical keyboard. To investigate the difference between them, an experiment was designed by Hoggan et al. The Palm Treo 750 with a physical keyboard and a Samsung i718 with a touch screen. To compare typing performance, a keyboard with the same size as a physical keyboard of Palm Treo designed for the Samsung phone [Hoggan et al. 2008].

Tacton sound played by touching the keys on the screen and the common keys to find ridges on the keyboard, "F" and "J" are distinguished by a longer Tacton sound. When users move their fingers on the screen, the sound played three times to allow users to identify their fingers slip on keyboard.

Twelve participants who had typing experience on mobile phones were chosen for the experiment. They were asked to type the given phrases quickly and accurately and submit them by clicking on "Enter" button. The experiment was done under two conditions: in the lab and a train while it was moving.

The ANOVA test shows a significant difference between physical keyboards, standard touch screen and touch screen with sound feedback. However, there was no significant difference between the number of correct words between physical and with feedback touch screen keyboard.

In addition, the results indicate no difference in typing accuracy when users move or stand stable. However, moving significantly increases the time taken to enter phrases, which might be because of trying to keep typing accurate.

Using the experimental results described above, another experiment has been designed by Hoggan et al. to test the performance of the actuator with localization compared with the physical keyboard. The sound was played with the same functionality as the above experiment. However, this PDA provides a ultimate feedback as well as the sound feedback.

The average number of correct phrases and number of keystrokes for generating a character for a word with one per character (KSPC) were not significantly different between physical and touch screen keyboard of the PDA. From both experiments' results, the authors concluded the vibration and sound feedback can bring the touch screen typing performance close to the physical keyboard speed [Hoggan et al. 2008].

Due to touch screen typing problems, Text Text Revolution game was introduced [Rudchenko et al. 2011] to improve users' typing skill. The game was designed to improve users' typing skill through lots of practice and finally resizing the keys based on user data to get less error.

Participants typed the words they were given and at the end of the game, they received a map which represents their touch points on the screen. The average speed and accuracy of typing were improved during twenty rounds of play. However, participants average accuracy for the first 10 rounds was upper bound 89%.

The first 10 rounds of participants' playing data were used as training data for resizing the keys and the second 10 rounds as test data set. The accuracy increased and the error rate decreased by 21.4% by key target resizing [Rudchenko et al. 2011].

1.3.3 RearTyping

RearType uses the reverse side of the device as its input text [Scott et al. 2010]. The standard QWERTY keyboard is used on the sides and back of the device to maximize screen available for showing output and to eliminate the onscreen keyboard, which covers the display by hands.

Thirty keys were installed on the back of each side of the device with Space, Enter, Backspace and Tab in a column on the front right side. Shift, Control and Alt have been placed under left thumb on the front. Also, a Mode key was designed to change the keyboard mode similar to touch screen keyboards and support other keys such as numbers and capital letters. (See Figure 1.2)

Figure 1.2: Back view of RearType prototype [Scott et al. 2010]

The study was divided into four steps: software familiarization phase, RearType training phase, touch screen familiarization and the experiment phase, which included five tasks. The experimental phase was repeated third times with approximately 350 characters to type each time.

The RearTyping speed for this experiment ranged from 9 to 47 words per minutes, which indicates different tutorial sessions should be adapted to each user. The average typing speed for RearType was 15.1 WPM, 21.2 WPM for touch screen and 72.1 WPM for a physical keyboard. Interestingly, this result indicated no significant difference between a touch screen keyboard and RearType. However, a significant difference was found between number of backspaces had been used, keyboard 14.9, touch screen 25.9 and RearType 44.8.

In addition to the qualitative results, qualitative variables were measured. The participants answered a survey question and they were asked to choose between touch screen and RearType input. Half of the participants preferred RearType. Participants were not satisfied with the device regarding its weight and grip design, which is reasonable since this device is a prototype [Scott et al. 2010].

We have discussed the advantages and disadvantages of using two different inputs for typing, touch screen and rear typing in the above sections. Typing speed, accuracy and having feedback are the main factors that have to be considered in designing a typing input for a new mobile device.

1.4 Playing games

Playing a game on mobile devices is another popular activity. People usually play with their phone or their hand held device to fill their free time and enjoy the time. Game performance depends on several fact such as keyboard size, keyboard type, screen size and so on. In this section, the effect of keyboard size and game inputs on users' performance are discussed in detail.

1.4.1 Keyboard size effects on game performance

The effect of screen size and keyboard size on game performance were examined [Morar and Kyritsis 2011]. The paper's authors looked at an action game for their experiment because of it was familiar to participants. The game was designed with three simple commands: left, right and fire.

Three ships were presented randomly and when users fired at them, they go to the next level which is more difficult. Participants played the game on the PC screen using the arrow key for control and on mobile screen with Joystick. The larger screen size interests users more, but it does not change their score significantly. The keyboard size has an influence on the game score, with lower scores the result of smaller keyboards [Morar and Kyritsis 2011].

1.4.2 Game controllers and touch screen devices

Two experiments were examined for comparing the efficiency of using game controllers and touch screen devices through a navigation task. The first experimental equipment includes Trackball, Gamepad, Cyborg, Sidewinder, SpaceExplorer, which are different game handles. Participants were asked to indicate the target that was focused on the display with their controller.

The results from twenty users show that playing with Cyborg and Sidewinder controllers was significantly faster than playing with Trackball. However, Gamepad and Trackball did not behave significantly differently.

The second experiment compares five touch screen devices' performance: Tablet PC, Wacom, Smartboard, TouchTable with 0 degree configuration and ToucTable with 30 degree configuration. Fourteen right handed users were asked to complete the navigation task three times for investigating the devices' learning curve.

The only significant difference was between time completing of Trackball and Wacom. In addition, there were more errors with playing with a touch screen device than playing with a game controller. However, no significant difference were found in terms of their completion time [Ogren and Wong 2010].

1.5 Navigation

Using online maps is more useful than using paper maps to find our way since it is easier and faster to search and they can be updated quickly. Carrying a mobile device is needed to use online maps. Small mobile devices' displays could affect navigation performance. In addition, it is important to investigate how much navigation is memorable, which is discussed in the section below.

Remembering maps is always a concern. Patrick et al. studied three different view conditions: head mounted screen, large projection display and a 21 inch desktop monitor. The authors measured the error rate of the layout participants drew after navigation on the maps with the actual map. Sixty seven participants with a different age range (18 to 33) were tested for their spatial perceptual ability and forty eight of them were selected based on their score [Patrick et al. 2000].

For the head mounted monitor, a Visette Pro head mounted monitor with (640) resolution had been used and for the PC monitor, a 21 inch Liyama Vision Master 500 model has been used. The projector screen was a Toshiba projector.

1.6 Screen Sizes

To keep mobile devices portable, designers are forced to use small screens. With small screen space there are other ways to deal with PDAs screen usage, which are described in this section. However, in spite of the small screen size dealing way, screen size still has effects on users' arousal, attention and performance.

1.6.1 Dealing with small screen space

Personal Digital Assistants (PDAs) usually have small screen sizes because of portability. A small screen reduces the ability of users to read small font sizes especially at low resolution. In addition, reduction in size of the display and less information in the display force users to have higher interaction with the device.

There are some ways to use the maximum amount of display: showing information structure more efficiently, showing the information content more efficiently, showing widgets more efficiently and semi-transparent widgets. A prototype was examined to find a more efficient way for using space in a small screen [Kamba et al. 1996]. The prototype had some labels, content, icons moves between stories, hypertext link and seven icons at the bottom for special tasks such as search or trash. Eighty percent of the screen was assigned to the context and twenty percentage of remaining to the icons. They found out that it would be easier for participants to use a variant of semi-transparency response model.

Another experiment was done [Brewster 2002] regarding dealing with the small space in PDAs screen. He tried to use sound for presenting buttons. The experiment was designed in two 7 minutes treatments for standard (16×16 pixels) and small (8×8 pixels) button size: visual and visual plus sound. The results illustrate a significantly higher preference in the standard buttons with sound than small buttons with sound and buttons without sound.

A concern in the use of sound occurs when the device is used in a noisy environment or when customers walk. Brewster designed another experiment in a real environment and asked participants to walk during the treatment. The amount of data entered in a real environment reduced in comparison with the laboratory environment. However, participants prefer buttons with sound even in the real environment. Finally, these studies suggested a high usability by using sound in PDAs [Brewster 2002].

1.6.2 Comparison on different screen sizes

The effect of screen size on users' performance has been investigated in many studies. One of the important screen effect is on users' social realism, attention, and arousal, which we will discuss in this section.In addition, screen size can affect on users' performance and readability that are major concerns in designing a (mobile) device and three studies are discussed here to cover. A case study at Cleveland State University [Bracken and Pettey 2007] examined the effect of screen size on users' immersion, spatial presence and social realism. The authors claimed a higher level of immersion, spatial presence and social realism with larger screens.

Two video clips from part of the Ronin movie were chosen including a 10 minute conversation and 10 minutes action. The action part had a fast pace versus the conversation part was presented at a slow pace. Participants watched the clips on a 32 inch television and on an iPod.

There was no significant difference in spatial presence and social realism between large and small screens. However, a higher level of immersion was achieved while users watched the clips on a larger screen. In addition, users who watched the conversation clip on a larger screen reported the highest level of social realism while participants who watched action clips on it showed the lowest rate of social realism [Bracken and Pettey 2007].

Three different screen sizes, 56-inch, 13-inch, a 2-inch, were used to investigate the effect of screen size on users' attention and arousal in Reeves's experiment [Reeves et al. 1999]. They measured attention and arousal by heart rate and skin conductance respectively. They had two main hypotheses in their study. The first hypothesis was that heart rate will be slower indicative of greater online attention, for messages presented on the larger screen. The second hypothesis was sympathetic arousal as increased skin conductance will increase as the screen size increases.

Thirty-eight females participated in the experiment because of their more emotional response than male. The results of their heart rate show that they paid more attention to the message on large screen rather than small or medium ones. Also, subjects' skin conductance responses shows higher arousal with larger screen [Reeves et al. 1999].

Another study [Findlater and McGrenere 2008] was done on 36 participants to compare a small screen with a desktop sized screen. In the experiments, subjects have to select a series of menus. Two types of menu were examined: static menu and adaptive menus with different accuracy. The static menu was a pull-down menu and the adaptive menus were designed as split menus.

On the small screen, all items in the menu cannot be shown at the same time therefore users had to click on scroll widgets to get access to them. The experiment task was designed as a sequence of menu selection once a user selects the menu correctly, the next one will be displayed. Users' speed as performance and users' recognition rate as awareness have been measured to investigate the experiment's hypotheses.

The results of the experiment suggest a significantly higher speed when using the selecting tasks in the menu on the larger screen and a higher awareness in large screen. In addition, comparing adaptive menus with different accuracy rate shows high accuracy menu (78%) was faster than low accuracy menus (50%) [Findlater and McGrenere 2008].

The effects of screen size on readability were studied at the Texas A&M University [Kingery and Furuta 1997]. The authors also examined typeface, point size and screen resolution in their study. Twenty-two male and six female subjects participated in the experiment with an average age of 19. Among three font sizes, 14 points, 20 points and 24 points, the 20 points size provides the highest average of correctly typed words.

The results show a significant difference in the number of words of headlines in three font sizes and the 20 points size provided the best combination of inter-character space and word's shape. The low mean for 24 points size might be because of the larger area a word occupies on the visual surface and so has less important information.

Subjects' preference were also presented in this paper for the screen size and resolution. They preferred 19 inch displays over a 14 inch monitor. Subjects with the lowest favourite preference show no significant difference between the two resolutions and after analysing the 24 points size different font types, it was found out that there was no significant difference between the means of the typefaces [Kingery and Furuta 1997].

In the above section, we have compared different screen sizes and discussed the problem with small screen. From those studies results we concluded that choosing a right size screen is an important factor for designing a device and we need to consider that in out tablet design. However, those studies only rely on non-touch screen displays therefore, it is worth studying touch screens, which is discussed in the following section.

1.7 Touch screens

There are a large number of inputs for mobile devices. The touch screen is becoming the most popular one and is replacing other inputs such as mouse, keyboard. However, using a touch screen does not always improve users' performance and it causes some problem for users while they are using it. This section tries to first compare other input device performance with touch screens and then nominates touch screen issues.

Table 1.1: Experiment Target Combination

Target Type	Target Size	Target Angel	Target Distance
text box	$\angle 45$	large	40 mm
combo box	$\angle 135$	medium	60 mm
check box	$\angle 225$	small	80 mm
button	$\angle 315$	-	-

1.7.1 Mouse or multi touch

Designing a mobile device with touch screen brings limitations such as hand coverage on the screen as well as advantages over using a mouse or a keyboard. The effectiveness of a touch screen and a mouse regarding selecting various GUI items [Gleeson et al. 2004] .

The target sizes were selected by using Apple guidelines. The text box, button, check box and combo box were selected in three different sizes: small, medium and large. Twenty four participants were divided into two groups depending on their skill with using a mouse and touch screens. The participants with less experience with touch screens were allocated in a group which has to use the touch screen in the experiment. This division was based on their answers to the pre-survey questions.

The experiment was designed in six blocks including four possible target types, three sizes, four angles and three target distances (See Table 1.1), which resulted in 114 trials for each block of the experiment. Throughput, error rate and movement time have been measured during the experiment.

As mentioned above, the experiment was repeated six times therefore it is possible to investigate the learning curve. There was no significant difference between experiment blocks after the first block. This result shows that learning has been done in the first block and the last block has a capacity to show the performance better than other blocks.

The mouse was found on average 15.2% faster than a touch screen, the overall movement time for the mouse was 1.3s and 1.6s for the touch screen. In addition, the text box was the fastest target to select after the button. The check box and the combo box were placed the last. Interestingly, the touch screen acts 67% slower than the mouse only on small targets.

In addition, a double-side multi touch input device has been designed by Shen [Shen et al. 2009]. Two iPod touch devices were glued back to back and the back touch inputs were transmitted through a WiFi connection to the front. The device supports at most five touch points. In a user study, participants were asked to grab, drag, push, flip and squeeze. Participants found the double side device easy to learn and the time takes to perform on the double side device was the same as the time taken for the single sided device.

1.7.2 Touch screen and hand cover problem

The devices had no significant difference in throughput rate mouse (1.238) bps and touch screen (1.215) bps. Among the targets, check box reached the highest throughput rate however, the check box also had the highest error rate. The mouse error rate was 2.7% and the touch screen error rate was 60.7%. Overlay, touch screen as well as its slowest time on small target has the highest error rate.

From the questions asked from the participant after the experiment about their comfort, it was found that the mouse was significantly easier to point and arm fatigue was rated significantly higher on a touch screen (4.083) than in the mouse (3.167) [Gleeson et al. 2004]. Rather than the fatigue problem of touch screen devices, it is the friction between a user's fingers and the screen that may cause annoyance [Buxton et al. 1985].

In addition, finding keys for typing text on a small touch screen becomes harder when they are covered by the user's hand [Vogel et al. 2009]. Research shows up to 47% of a 12 inch screen can be covered by hand, pen and forearm and can cause errors, fatigue and unwanted movements.

In the Vogel et al. study, they found that messages which were shown near the bottom of the screen have more chance of being ignored. A large movement happened when users tried to drag a target to highlight that and they put their hand on the screen for resting.

A camera was installed on the participants head to video their hand occlusion during the experiment. The experiment participants were all right handed and had no clue of colour blindness. In addition, participants' elbow to fingertip and shoulder to elbow, upper limb and hand length and hand breadth were measured before the experiment.

They were asked to "tap" and "circle" the targets during experiment on a 12.1 inch direct input pen tablet. The tablet was located on the desk with a 12 degree angle. Taping was designed as a short time interaction that does not need hand's resting and circling was examined to investigate the participants' reaction to a long term interaction, which needs hand's resting.

Overlay, the experiment has 462 data points including 77 target positions for each task. They measured the mean error rate participants made, 4.4%. The highest occlusion ratio,the percentage of hands occluding pixels to the hole screen's pixels, which occurred when participants' pen was located at the top left of the display.

In addition, the highest value for the tapping task (38.8%) and circling (38.6%) was not significantly different. It was found that the participants' hand and arm size was not relative to the screen part which was covered by their hand. These problems might be resolved by placing the touch interface on the back of the device.

Finally they offered three suggestions: do not show messages on the right side of the pen or bottom right of the display and consider users' different pen grips [Vogel et al. 2009].

In this section, we investigated the touch screen problems and capacities, which gave us an idea to solve the touch screen problem by putting a magic trackpad at the back of the device. In the following section, there are some new ideas for using the iPad touch screen devices in order to improve users' performance.

1.8 Other iPad's usages

There are other studies related to our work on the iPad and measuring users' hand performance on touch devices. A double sided multi touch input device has been designed using two iPods. Users are able to grab, drag, punch, flip and strength in different directions on the device. The device prototype was examined by three users and they found the gestures easy to learn [Shen et al. 2009].

In a recent paper, the authors combined two iPads back to back together and designed a front and back device to see whether seeing our actions as a human feedback improves users' performance or not [Wolf et al. 2012]. They implemented a software to track finger movement, tap and drag.

They measured participants' finger addressability, front and back screen mapping, pointing precision and positional pointing accuracy in the experiment. The experiment asked users to do an initial pinch, rest pinch, make circles with thumb and dragging thumb.

They found that users can perform thumb-based pointing to the fingers from the back of a device with high precision. In addition, they could synchronous thumb tap with a finger with high accuracy.

After the news of the upcoming iPad 2, a boy fantasizes about a 27 inch screen as an iPad 2 [web a]. He used it for different usages in his video on YouTube like listening to music, taking photos, editing pictures and so on. This is not a real device or even a working mock-up and cannot be tested (See Figure 1.3).

Figure 1.3: 27 inch screen iPad2

In addition to the 27 inch screen iPad, Marton a student in Hungary designed a concept of an Apple e-book reader device. He tried to design a device which is like traditional books with two sides touch screen. It has other functionality at the same time like listening to books, downloading the book and browsing the web [Perhinik 2010].

As discussed above, there is other work trying to improve the iPad usage or use the iPad for different applications. An important factor in designing a new device is to consider ergonomic issues. We have studied the possible ergonomic issues that were related to our device and designed a user study to investigate its ergonomic issues. The next section is a summary of project related ergonomic research studies.

1.9 Handedness

A large number of devices have been designed in a way that it is easier to use for right handed people. In our project, the new mobile device with its bigger screen and a trackpad on the back has to be examined to find the most comfortable design regarding holding the device and moving the mouse. In this section, we look at the difference between people's hand performance, hand grip strength and the factors that impact on these.

1.9.1 Dominant and non dominant hand's performance

Handedness is an important aspect to consider when designing PDAs. In a hand preference questionnaire, male and female participants did not show any differences in their preference hand [Annett 1970]. He investigated that handedness is not discretely distributed and is continuous. In addition, he examined the relative movement speed of the left and right hand.

Three different groups of participants were gathered from the University of Hall. The first group was 460 psychology students, the second group included 630 servicemen and the third group were 1232 non-psychology students at the University of Hall. Then they were divided by gender, psychology or non-psychology students and questionnaire version 2 or 3.

Questionnaire 2 includes twelve questions about twelve actions and subjects have to answer the hand they use to complete the action,"right", "left" or "either". However, questionnaire 3 does not have "either" answer therefore, fewer participants in this experiment were given this questionnaire type. The actions were the same for both questionnaires (See Table 1.2).

Out of the questionnaire subjects' answers, 664 mixed handers were distinguished. It was found that handedness could vary from 6 to 17 percent for different actions. Writing had the least percentage of "either hand" preference and a number of actions were performed with the left hand even less than writing. Interestingly, cutting with scissors had the most "either" response than other actions.

Three answers, "left", "right" and "either" were analysed separately and correlation between the actions were calculated. As the result, six actions, A, B, C, D, J, and K, were highly associated and unscrewing the jar lid action showed the lowest association with other actions. However, other five actions were banded in same groups.

Table 1.2: Questionnaire 2 and 3 actions

Action	letter
Writing	A
Dealing cards	I
Unscrewing jar	L
Shovelling	H
Sweeping	G
Threading needle	F
Striking match	D
Throwing ball	B
Hammering	J
Using toothbrush	K
Using racket	C
Using scissors	E

In this experiment's results 23 types of handedness have been found. The sweeping and shovelling actions were highly associated and have the possibility to be interchangeable. Finally, the author suggests writing as a base of divisions that have a low error rate.

In the second experiment, 118 undergraduate students and 156 twelve years old teenagers were used a tool to complete the actions manually. Participants had to dowel pegs into 0.5 inch, 1 inch and 8 inch holes as a trial and then perform the first experiment actions. The results show a significant higher speed in using the left hand for left handers and the right hand for right handers with no difference between left and right in mixed handers [Annett 1970].

Another study [Nalcaci et al. 2001] investigated the relationship between sex difference and hand performance between 310 right and left handers. Participants had no history of psychiatric or neurological illness and they were classified into right and left handers base on various actions.

The experiment was demonstrated to the subjects then they were asked to tap with their index finger as fast as possible for 10 seconds, three times. The participants had to keep their hand on a wooden rectangular plate during the tapping task. The average number of taps for each hand was measured as speed. Also the tapping speed difference between the right and left hand were calculated based on the formula below:

$$\frac{\text{Right hand speed} - \text{Left hand speed}}{\text{Right hand speed} + \text{Left hand speed}} \times 100 \tag{1.1}$$

Tapping rate was higher for the right hand than the left hand in every group: left handed, right handed, female and male. However, left handers obtained a higher tapping rate than right handers. The sex difference also showed a higher rate among men than women [Nalcaci et al. 2001].

Using the dominant or non dominant hand or using both at the same time usually affects the users' performance. A tabletop device was designed that allows users to manipulate virtual 3D models to observe humans work distribution between two hands [Cutler et al. 1997]. Navigation and manipulation tasks can easily be done with training using two hands.

Various groups, right handed, left handed, mixed handed, male and female, users perform differently. A good design has to satisfy a large number of people. Therefore, considering the above studies results may contribute to a more comfortable design.

1.9.2 Handedness recognition

Usually the preferred hand is considered to be the hand with better performance in common actions like writing. A study on hand preference [Kimura and Vanderwolf 1970] shows that handedness is not recognizable based on the accuracy of a movement control. The study examined 48 normal subjects that were tested eight tasks: write, brush teeth, hammering, combing, bread cutting, using key, striking a match and holding a racquet. Then based on their test results, they were classified as right and left handers.

In the first experiment, subjects had to randomly move their eight fingers at the middle joint to approximately 90 degrees without moving any other finger. For the second part of the first experiment, they were asked to move two fingers on one hand's together. The experiment was run up to three times if the participants made a mistake in their movement.

However, participants who make the movement right, score the highest. A score of 3 for the first correct trial, 2 for the second trial, 1 for the third and 0 for none of them. The results showed that right handed subjects score higher than left handed. Interestingly, the left hand of every subject except female left handed participants works more accurately than their right hand.

This experiment was run with a different group of participants, the same results were obtained except left hand did not show any preference over the right hand in the single finger movement. Finally, the authors suggest no relationship between fine movement and hand preference [Kimura and Vanderwolf 1970].

1.9.3 Grip strength in dominant and non dominant hand

Using the dominant hand for gripping or pinching is significantly different from using the non dominant hand [Incel et al. 2002]. 149 participants, including 128 right handed and 21 left handed users' grip and pinch force were measured. The participants had no history of joint illness or any injury to the upper body by their report. A manual pinchmeter was used to measure the pulp pinch strength between the first and the second digits. The paper [Incel et al. 2002] documented stronger right hand strength for right handed subjects, but they did not observe significantly stronger left hand in left handed subjects. This may be due to the large number of activities requiring the use of the right hand in daily life, so left handed people are obliged to use their right hand as well as their left hand.

1.9.4 Grip strength and age, height and weight effects

Age, height and weight have effects on grip strength. A study [Newman et al. 1984] on 5 to 18 year old school students in Australia has been done to investigate these effects. 739 boys and 678 girls students were participating in this study. A demonstration of the test and instructions were given to the participants before they start the experiment.

Two readings were given to participants during each hand's squeeze and they had to squeeze the handles of a dynamometer while reading. Dynamometer can show a range of 0.5 N to 1500 N force. It has a steel U shaped handle and when the handle is griped, the electrical resistance changes and it causes the force.

Weight, height, age, readings were documented as well as the subjects handedness. The results show an increase in boy's hand strength when they grow from 5 to 18 years old. In spite of the boys, girls' strength only increases up to the age of 13 and remained constant up to the age of eighteen years.

In addition, boys illustrate 60% higher hand grip strength on average than girls. Investigating the influence of height and weight on girls participants' hand grip suggest 0.99 (of a unit) hand grip increase or decrease for each Kg less or more weight than the group's age average weight. However, finding the influence of weight and height is more complex than a linear relation so it needs more research [Newman et al. 1984]. In addition to the effects of height on grip strength, height also effects lifting strength [Lee 2004].

Another study [Peebles and Norris 2003] has been done to cover a number of gaps that exist for designing a device without any ergonomic problems. These are finger punches strength, pinch-pull strength, hand grip strength, wrist-twisting strength, opening strength and push-pull strength.

Participant from 2 years old to 86 years old did six test experiment. The 150 subjects were grouped based on their age. They were asked to stand in front of the measurement device and push their dominant hand's index finger or thumb on the force position, forward and downward.

For the second test, participants pinched three different handle sizes, which were installed on the measurement device. Then they griped the handles and a dynamometer measured their hand grip. For the twisting test, subjects twisted their dominant hand in a clockwise direction of a door lever, door knob, ridged knob, circular knob, tap and butterfly nut. Opening users' hand strength were measured when they opened three jar lids (45 mm, 65 mm, 85 mm) and for the last test, push and pull, a 30 cm cylindrical bar were used in different orientations. The participants had to pull and push the bar with their highest force and between each test, participants had a two minutes rest to avoid fatigue effects.

Analysing data of every test showed significant stronger hands for adult men than adult women age over 16 ranging from 55% to 75% and interestingly no significant difference between their maximum hand strength. An increasing hand strength curve from childhood to adulthood was investigated and then falling from 50 years old. Children from 6 to 10 years old were similar to the adult age over 80 years and adult from 60 to 80 acts similar to children between 11 and 15. These results can help inform device design for a more general population [Peebles and Norris 2003].

1.9.5 Tapping performance and dominant and nondominant hand

Grip strength and fatigue have been studied in three different experiments not related to PDAs with 51 college students including three left handed. To avoid age and physical body's effects on the experimental results, the participants were selected in the range of 18 to 33 years old.

A dynamometer system with an electromyograph sensor have been used to measure the hand grip force muscle activities. The participants were seated in front of a table resting their elbow on the table with between $\angle 90$ and $\angle 120$.

The experiments were with single tapping repetition, 10 tap repetitions and 30 second grip hold. Subjects squeezed the dynamometer for less than 2 seconds for single tap test, 10 squeeze in 20 seconds for 10 repetition test. In all experiments, the grip strength of the dominant hand was significantly higher than the non dominant hand, but with the passing of time spent gripping, the difference reduced [Nicolay and Walker 2005].

Also fatigue in the dominant hand becomes more than in the non dominant hand during the experiments. Males always have larger average grip strength than females, which is expected because of their larger average body size [Nicolay and Walker 2005].

In another study [Van Strien and Bouma 1988], it was found that the tapping performance of dominant hands is higher than with non dominant hands. Single and sequential tapping performance of 60 left and 24 right handed university students were measured in two conditions: dual task and no load.

Dominant hand performance was significantly higher than the non dominant hand in both single and sequential tapping tasks under no load condition. In the single tapping experiment all dual task conditions significantly decrease tapping performance compared to no load condition. However, in the sequential tapping experiment only the reading task reduced performance [Van Strien and Bouma 1988].

Tapping with right or left index fingers has significantly different strength [Peters and Durding 1978]. They asked users to tap as fast as possible. Handedness differences in performance were found while participants were tapping. The average tapping rate of the right hand was found to be higher than left hand in both right and left handed groups.

Interestingly, left handed participants were faster than right handed ones while they were taping. This shows the weakest hand is the left hand of right handed people [Peters and Durding 1978]. In the study above a significant gender difference was found in tapping performance. The authors found men's tapping speed was faster than women's speed, which was verified by Schmidt's [Schmidt et al. 2000] results.

1.10 Summary

In this section, we have gathered studies around screen sizes, their difference and touch screen that helps us having a higher understanding for designing our device. In addition, we have discussed the ergonomic issues for gripping and tapping on the device. Testing the device is also important, which should be done through some tasks.

Mobile devices are useful for different applications such as: reading, typing, playing games, navigating through maps and so on. Therefore, we mentioned some research around these popular tasks to be more familiar with the selected tasks. Considering these studies approach lead us to design a device with more functionality and higher performance.

Chapter 2

Comparing User performance of an iPad and BackPads

The Apple iPad is commonly used for reading news, magazines and text books, playing games, web browsing, etc. [Nguyen and Chaparro 2010]. The idea of a bigger screen with a pad at the back instead of a touch screen arose due to the iPads known issues regarding typing, playing game and reading on small screens, [Bergman 2000] [Hoggan et al. 2008] [Kärkkäinen and Laarni 2002] [Sears et al. 1993] [Waycott and Kukulska-Hulme 2003] and difficulties with touch screens [Hoggan et al. 2008] [Gleeson et al. 2004] [Buxton et al. 1985].

A device with new functionality is introduced. It has a large 17 inch screen and a touch pad is installed at the back of the device, hence we call it a BackPad. As we observed in my experiment, none of the subjects hold the device with one hand and press the keys for applications with the other hand. Subsequently we will not differentiate these two unless germane to the discussion, that is, we will only refer to the size of the device.

In this work, we focus on a user study comparing my 17 inch BackPad and the iPad, my 13 inch BackPad and iPad and front and back touching users' performance with respect to typing, game playing and navigation task performance. we expect to reach the best performance and results among using the 17 inch BackPad, the 13 inch BackPad and the iPad.

In addition we did another user study to compare the front touch screen input of the iPad and the Back input of our BackPad. However, to have a consistent factor for comparing input, we also designed a 10 inch BackPad and compare that with the iPad. we expect that back input would have better or same performance than front input.

2.1 Comparing User Performance of an iPad to a 17 BackPad

The 17 inch BackPad that we have designed has a 17 inch screen size and a trackpad at the back of the screen to control the cursor on the screen. In this section, design of hardware is discussed following by the tasks that are designed to examine the device and participants' characteristic. Finally, results of the experiment is shown and conducted.

2.1.1 Design of Hardware

In order to conduct a user study on the big screen device, we designed and developed a 17 inch BackPad. The device (Fig. 2.1) has a 17 inch non touch screen display (Fig.1.2) and a (Bamboo [web c]) touch-pad is installed at the back of the screen (Fig.1.4). The display we use is a semi-separated screen of a 17 inch Mac-laptop. we could not readily relocate the Mac-laptop touch-pad so needed to use an extra touch-pad. Participants (Fig.1.1) hold the screen with their hands and they use the touch pad at the back in order to move the cursor on the screen (Fig. 2.2).

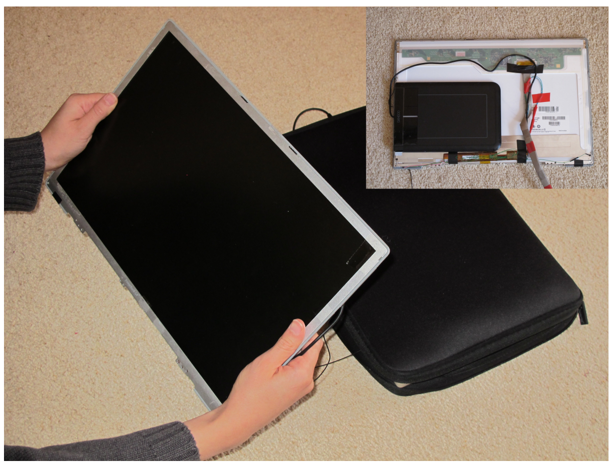


Figure 2.1: Device setting: (1) Participant, (2) 17 inch BackPad (we.e. semi-detached laptop screen), (3) Monitor cable, (4) Bamboo touch-pad

Figure 2.2: View of the device from behind

The touch-pad can be flipped for left handed or right handed use. Right or left handed users are a factor in positioning the touch pad. Although by changing the position of touch pad to the left of the screen, left handed users can participate in the experiment, we chose to limit the experiment to right handed users and left studying left-handed users for future work.

The hand covering part of the view problem of touch-screens [Vogel et al. 2009] is eliminated by the positioning of the touch-pad at the back of our device. The thumbs remain at the front to hold the device and cannot be used for touching the back touch-pad. There is a potential issue with user performance with their fingers behind the device. Wobbrock [Wobbrock et al. 2008] found that the index fingers perform better at the front than at the back for complex gestures, and functions just as well as at the back for simple tasks.

2.1.2 Design tasks

Sixteen subjects participated in the experiment, considering the sequence of use of the devices, and the sequence of experiments; the tasks were typing and playing a game and there are two different devices.

we want a simple paragraph for the typing experiment. A paragraph from a childrens story book [R. Goscinny 2011] was given to users to type in both devices. The paragraph complexity level is for a person who passed at least 6 years of education based on the Flesch-Kincaid Reading Ease method [Flesch 1948]. The Mac laptop has an on-screen keyboard [web g] but it does not cover the whole width of screen so we installed the Big Screen Keys application [web h] on the Mac laptop. The iPad was oriented horizontally to have more space for its on-screen keyboard.

In this experiment we did not want external factors to affect the experimental results so we looked for two games on the iPad and Mac with similar interfaces. There are a large number of game applications for Mac laptop and iPad but only a few of them have very similar interfaces in both devices which are used in this experiment. we used a game which requires only a mouse / trackpad because there is only a touch pad at the back of our device and using keys or keyboard arrows is beyond the purpose of our thesis. We chose the game 4 in a row [web e] for two further reasons; first for its very similar interface in both the Mac and iPad, and second because it is easy to learn.

2.1.3 Participants

For evaluating an interface, it is necessary to test the interface under some particular experiments by a number of users. The number of users required depends on the design of the hypotheses and the experiments in the project. The sequence of using devices might affect the results. To avoid this, in our experiment half of the users first used the iPad then the big screen, and vice versa. Furthermore, in each of these, half of the subjects played the game first then went on to the second experiment; we.e. typing.

Sixteen students from a local university participated in the user study. The user study included 10 male and 6 female right and handed participants, ranging from

18 to 31 years of age (Mean = 23, SD = 3). All participants were regular computer users (Computer Science, Engineering and IT students). A few participants often use iPad for playing-game and typing. Most of them have never used an iPad for typing. Fig. 2.3 shows previous use of an iPad and using it for playing games and typing for the 16 subjects who participated in the experiment.

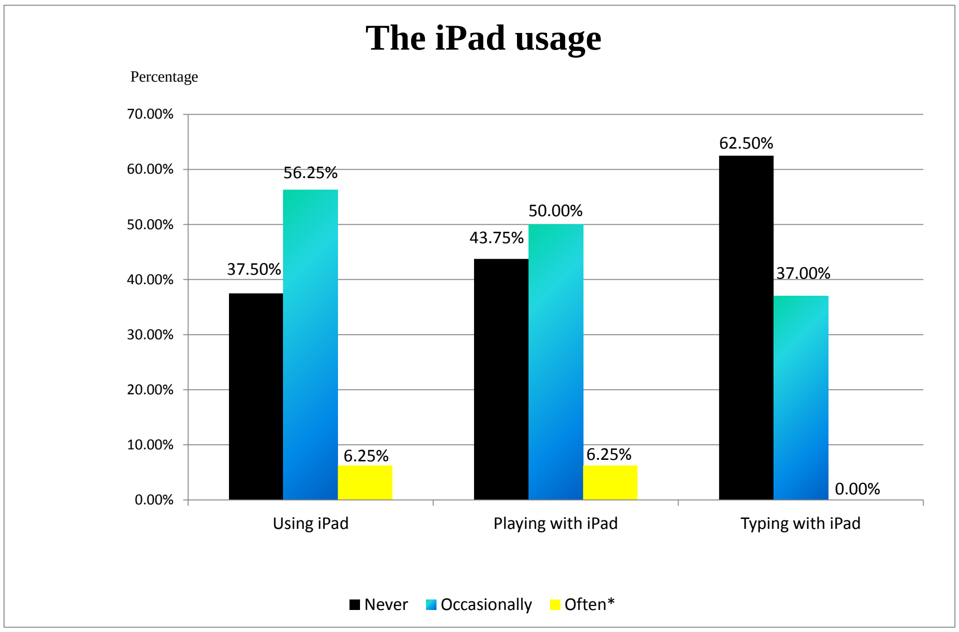


Figure 2.3: The iPad usage among 16 participant subjects in the experiment,
$*$ Often is more than 1 hr/day

2.1.4 Results and Discussion

The Paired T-test (2-tailed) showed a significant difference in time between typing in BackPad and iPad, T(15) = -10.6, P = 2.405e-08. Fig. 2.4 shows overall mean time for each device. It is clear that using BackPad for typing (Mean = 915.1, SD = 299.9) in the experiment on average participants take significantly more time than using an iPad (Mean = 118.9, SD = 33.1). But for spelling errors in typing the paragraph, the Paired T-test was done which shows no significant difference, T(15) =1.5, P = 0.1639, between the BackPad and iPad.

In addition, the Paired T-test (2-tailed) for the time spent by participants on playing the game does not show any significant difference. This means that playing a game on the BackPad and iPad have similar results, T(15) = 0.7, P = 0.5185. Furthermore, the comparison of the mean of time spent, as illustrated in Fig. 2.5, shows that

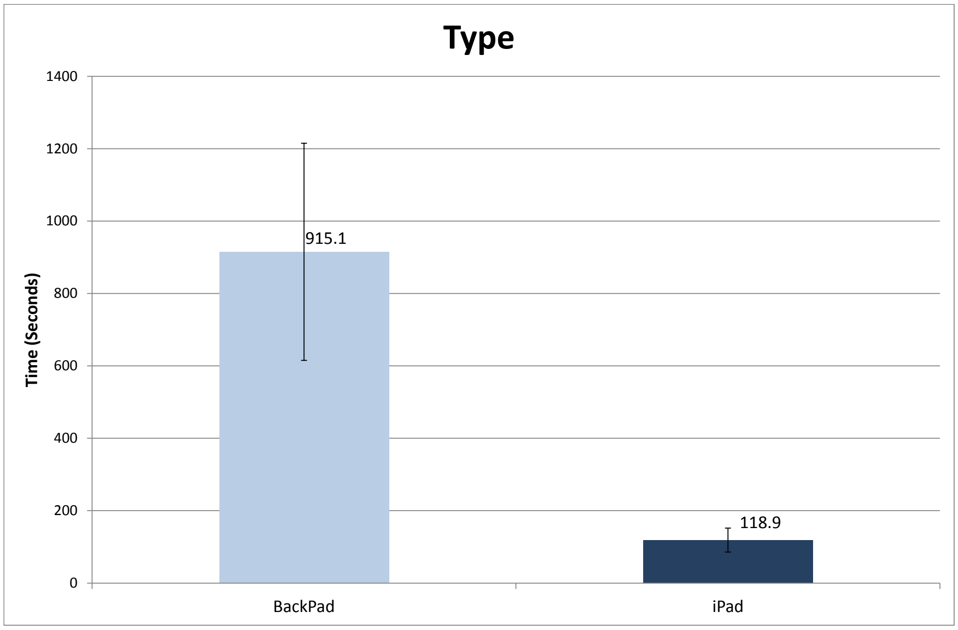


Figure 2.4: Mean type time for each device in the experiment

the results the participants achieved in using the BackPad (Mean = 79, SD = 61.2) for playing the game is the same as using the iPad (Mean = 65.2, SD = 40.0) in playing the game.

From the result of the Paired T-test (2-tailed) for the subjects' game in the experiment we found that there is no significant difference in their score between the BackPad (Mean $= 0.4$, SD $= 0.5$) and the iPad (Mean $= 0.6$, SD $= 0.5$), T(15) $= -1.4639$, P $= 0.1639$. The score for the game was counted as zero for losing the game and one for a win. It should be noted that there are were draws in this experiment.

The results show that typing is slower on the BackPad but game playing is not slowed. From participants' comments we realized that they prefer to play game on the BackPad due to its big screen that is, the BackPad is more desirable for playing games.

We also surveyed participants to complement the quantitative measures we reported above. The questions in the survey are about "naturalness", "ability to play the game and type on the BackPad" and "complete the game and typing" in comparison to the iPad. Each question has a 7 point Likert scale from 1-Strongly Disagree to 7-Strongly Agree.

The results of questions from the survey regarding the experiment using the BackPad are represented in Fig. 2.6 which shows the results from the 16 participants. In

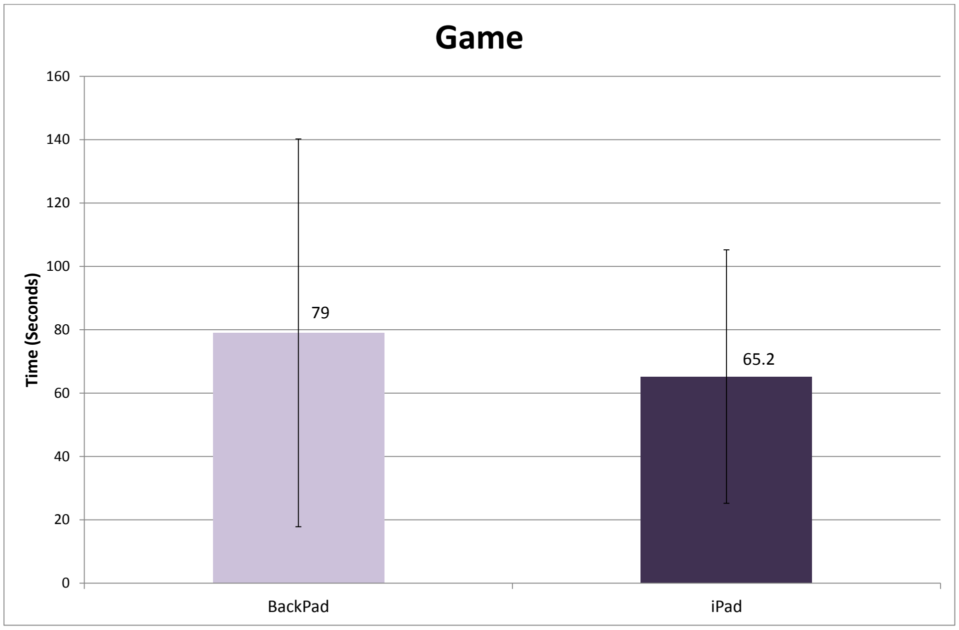


Figure 2.5: Mean play game time for each device in the experiment

addition, a question at the end of the survey was asked regarding their comment. The participants did not like the device for typing however, it was more pleasant for them to play the game with that device. They suggested some other usages such as listening to music or reading books.

Users did not on average find the device natural on first use, but were very able to play the game on the device. The survey results in general support our quantitative results.

2.1.5 Conclusion

From the results of both objective and subjective measures from the experiment, we demonstrated that typing with iPad is significantly faster than the 17 inch BackPad. The participants play the game with iPad as fast as the 17 inch BackPad, without any pre-training. Also their score in the game is statistically no different from the 17 inch BackPad, and they mentioned that they are more interested in playing games with the 17 inch BackPad in their comments. Therefore, the 17 inch BackPad is a desirable device in order to play games.

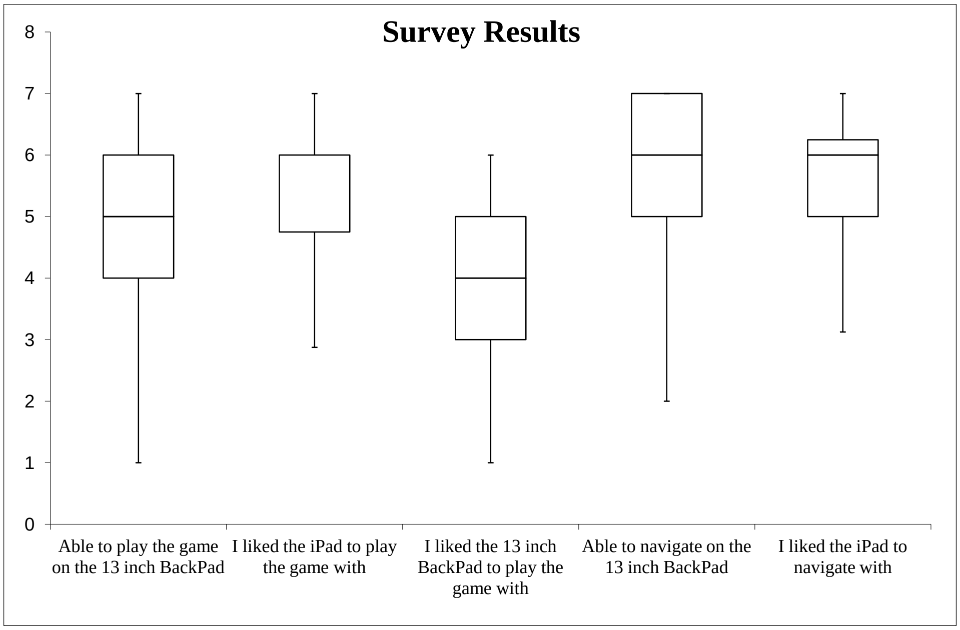


Figure 2.6: Survey results for the experiment
(7- point scale: 1 Strongly Disagree to 7 Strongly Agree)

2.2 Comparing back and front users' touch performance

In order to compare front and back input on a mobile device, we have designed a user study and a device. The device hardware and software used to conduct the user study are discussed in this section. Two different tasks are prepared for the user study which are talked about in the section following by the participants' characteristic and conducted results.

2.2.1 Design of Hardware and Used Software

In order to conduct this experiment we need to design a device with a 10 inch display and a track-pad at the back to compare it with 10 inch iPad with front (touch screen) input. The device (See Fig. 2.7 and Fig. 2.8) has an installed magic trackpad [22] at the back.

Since the installed magic trackpad is reversed to stick at the back of the device, the mouse directions mirrored. It means that by moving the mouse to the right, it goes to the left and vice versus also up and down do not work correctly. An application, "AutoHotKey", was installed on the laptop which mirrored the directions. Therefore, each time the participants tend to start the experiment, the application were run. In this way, the subjects perform the tasks on the device correctly with the right direction.

The device's display is a USB Powered Portable Dual 13 inch External Monitor. The monitor is connected to a Dell Latitude laptop with a VGA cable and a USB cable, which provides monitor power. Since the display is 13 inch, we blacked the background of the screen and only used the 10 inch middle part of the screen. To make the experiment devices consistent, we extend the iPad size to 13 inch. A 13 inch board is glued at the back of the iPad.

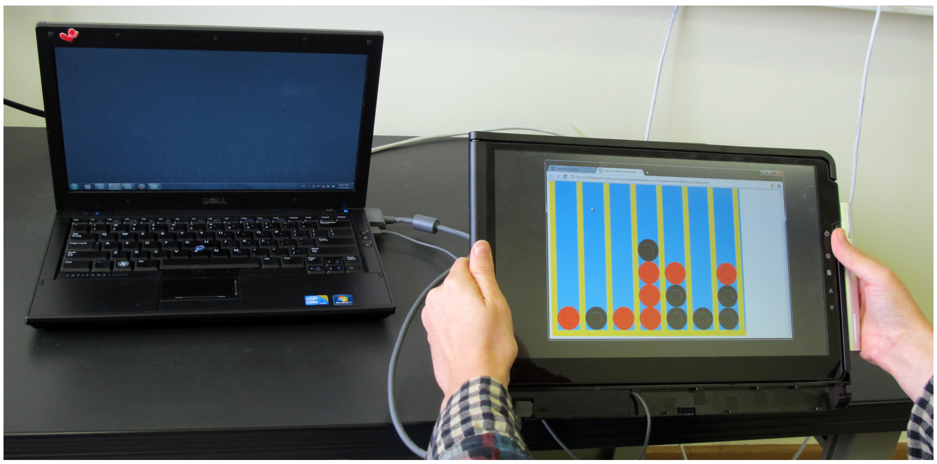


Figure 2.7: The Device Setting: (1) Dell Latitude laptop (2) Participant, (3) 13 inch monitor (the 10 inch BackPad interface), (4) VGA cable, (5) USB power cable

The 10 inch BackPad (865 gr) and the iPad (601 gr) weights are not equal. In addition to the display weight, we have the magic track-pad (140 gr) weight for the 10 inch BackPad plus two track-pad AA batteries (24 gr each). To make the devices weights equal, we added an extra (442 gr) weight to the attached board of the iPad.

Figure 2.8: View of the 10 inch BackPad device from behind

We chose to place the track-pad at the right side of the 10 inch BackPad so it is only usable for right handed subjects. It could be flipped for left-handed subjects but

Table 2.1: Experiment eight different sequences

Experiment Sequences			
Play game on the iPad	Play game on the BackPad	Type on the iPad	Type on the BackPad
Type on the iPad	Type on the BackPad	Play game on the iPad	Play game on the BackPad
Type on the iPad	Play game on the iPad	Type on the BackPad	Play game on the BackPad
Play game on the iPad	Type on the iPad	Play game on the BackPad	Type on the BackPad
Play game on the BackPad	Play game on the iPad	Type on the BackPad	Type on the iPad
Type on the BackPad	Type on the iPad	Play game on the BackPad	Play game on the iPad
Type on the BackPad	Play game on the BackPad	Type on the iPad	Play game on the iPad
Play game on the BackPad	Type on the BackPad	Play game on the iPad	Type on the ikPad

we left them for future work.

2.2.2 Design Tasks

We have done this experiment on sixteen different subjects from the first experiment, comparing iPad and 17 inch BackPad, but the sequences and the tasks was the same as that experiment. The experiments sequences we considered for this test is shown in the Table 2.1.

For the typing task, the same interface and same keyboard layout is used for both devices. (See Fig. 2.9) Two different paragraphs with the same number of words (39) were chosen from children's story books for the typing task. We asked participants to not correct any errors they make. Auto capitalization, auto correction and keyboard sound feedback also are turned off in both devices. In this way we would have the raw number of the errors users made.

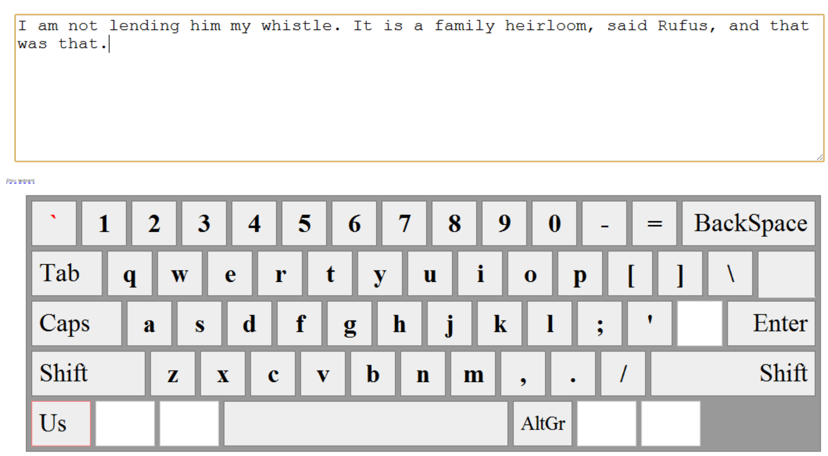


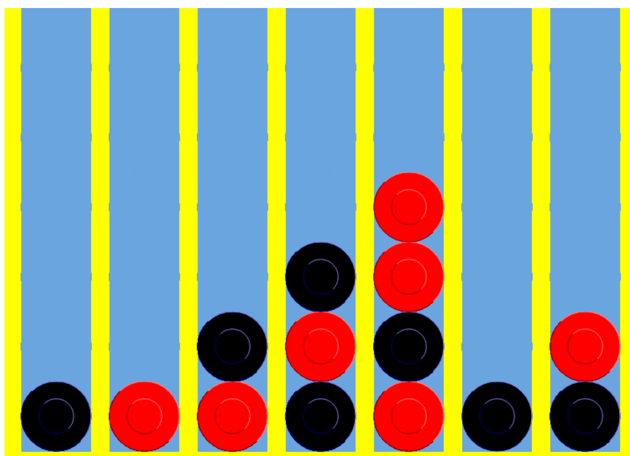
Figure 2.9: The iPad and the 10 inch BackPad the typing task interface and keyboard layout

One paragraph is used for the iPad typing task and a different one for the 10 inch BackPad typing task. We decided to have two different paragraphs [R. Goscinny 2011] [Goscinny and Semp 2006] to avoid learning affects in the experiment [Lazar et al.

2009]. The first paragraph's complexity level is for a person who passed at least 6 years of education based on the Flesch-Kincaid Reading Ease method [Flesch 1948] for the iPad. The second paragraph is for a person with at least eight years of education. Our participants were university students that already passed at least 12 years of education, so both paragraphs are "easy" to understand.

In addition to the typing task, we had a game task in the experiment. The "four in a row" game was chosen to be consistent with the first experiment. To have exactly the same interface for both devices, we prefer to use an html version of the game for the devices. (See Fig. 2.10) The Four in a Row game [Spelchan 2010] source code was customized to be fitted to both screen devices.

Figure 2.10: The iPad and the 10 inch BackPad 4 in a row game interface



2.2.3 Participants

By considering the experiment tasks, devices and sequences, we needed 16 participants to take part in the experiment.

Sixteen computer science and mathematics post graduate students from a local university participated in the user study. The user study included 7 male and 9 female participants, ranging from 23 to 40 years of age (Mean = 26.6, SD = 4). Participants were right handed and regular computer users and they were not paid for participating in this experiment.

They were asked to sit on a chair and adjust its height to the table in front of them. The experiment procedure were explained to them beside a trial session. In the trial session, they were asked to write their first and family name using the device and also play with the game (4 in a row) if they were not familiar with the game.

From the survey answers, it was found that none of these participants group often uses iPads for playing-game and typing. Most of them have never used an iPad for typing. Fig. 2.11 shows previous use of an iPad and using it for playing games and typing for the 16 subjects who participated in the second experiment.

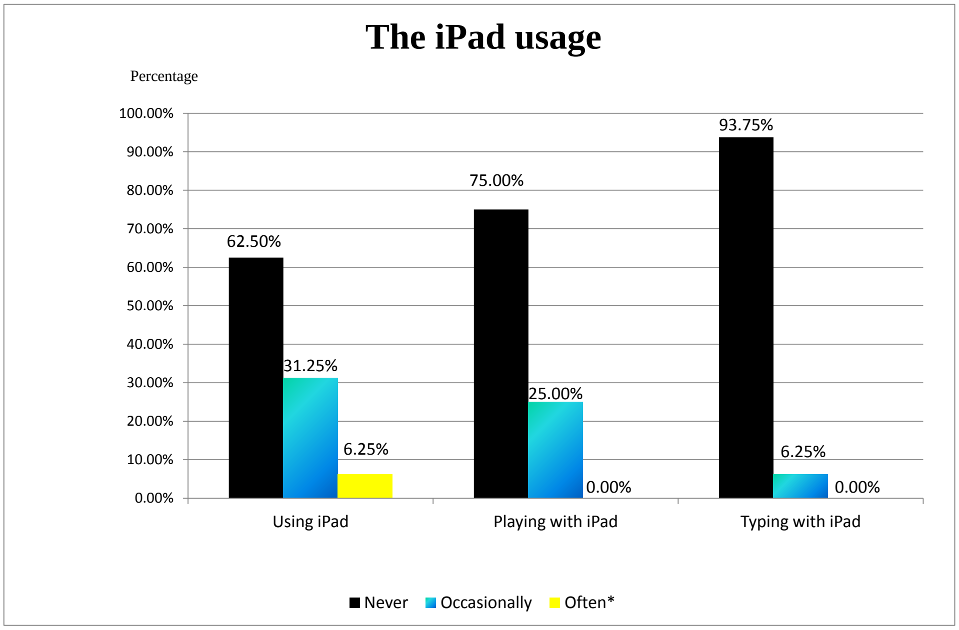


Figure 2.11: The iPad usage among 16 participant subjects in the experiment,
$*$ Often is more than 1 hr/day

2.2.4 Results

The Paired T-test (2-tailed) showed a significant difference in time between typing at the back and at the front in the iPad, T(15) $= -12.0$, P $= 4.333e - 09$. Fig. 2.12 shows overall mean time for each device. It is clear that typing at the back (Mean $=$ 466, SD $=$ 125.9) in the experiment on average participants take significantly more time than typing in the iPad (Mean $=$ 144.4, SD $=$ 31.0). For spelling errors in typing the paragraph, the Paired T-test was done which shows a significant difference, T(15) $= -2.4$, P $=$ 0.02985, between the back and front.

In addition, the Paired T-test (2-tailed) for the time spent by participants on playing the game does not show any significant difference. This means that playing a game on the back 10 inch device and iPad have similar results, T(15) $= -1.6$, P $=$ 0.1257. Furthermore, the comparison of the mean of time spent, as illustrated in Fig. 2.13, shows that the results the participants achieved in playing game by using back track-pad (Mean $=$ 45.8, SD $=$ 18.9) is the same as using the iPad (Mean $=$ 61.6, SD $=$ 41.4).

From the result of the Paired T-test (2-tailed) for the subjects' game in the experiment we found that there is no significant difference in their score between the Back 10 inch (Mean = 0.44, SD = 0.5) and the iPad (Mean $=$ 0.38, SD $=$ 0.5), T(15) = -0.4, P

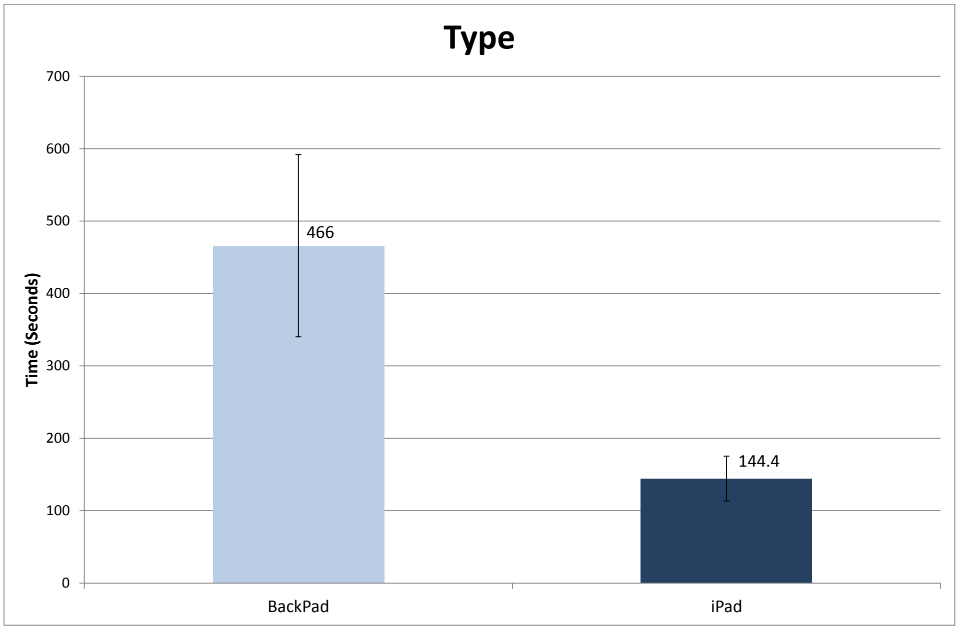


Figure 2.12: type time for each device in the experiment

= 0.7183. The score for the game is counted as zero for losing the game and one for a win. It should be noted that there are no draws in the second experiment. We asked participants to play again if that happened.

We also surveyed participants to complement the quantitative measures we reported above. The questions in the survey are the same as first experiment and about "naturalness", "ability to play the game and type on the Back 10 inch" and "complete the game and typing" in comparison to the iPad. Each question has a 7 points Likert scale from 1-Strongly Disagree to 7-Strongly Agree.

The results of questions from the survey regarding the experiment using the Back 10 inch are represented in Fig. 2.14 which shows the results from the 16 participants.

The participants comments were collected at the end of the survey. They were not satisfy with typing at the back however, no comments received about playing game. Generally, users again did not on average find the back natural on first use, but were very able to play the game on the device. The survey results in general support our quantitative results.

2.2.5 Conclusion

From objective and subjective results on our 10 inch Back and the iPad with front touch screen, we demonstrated the same results as the first experiment. There is no

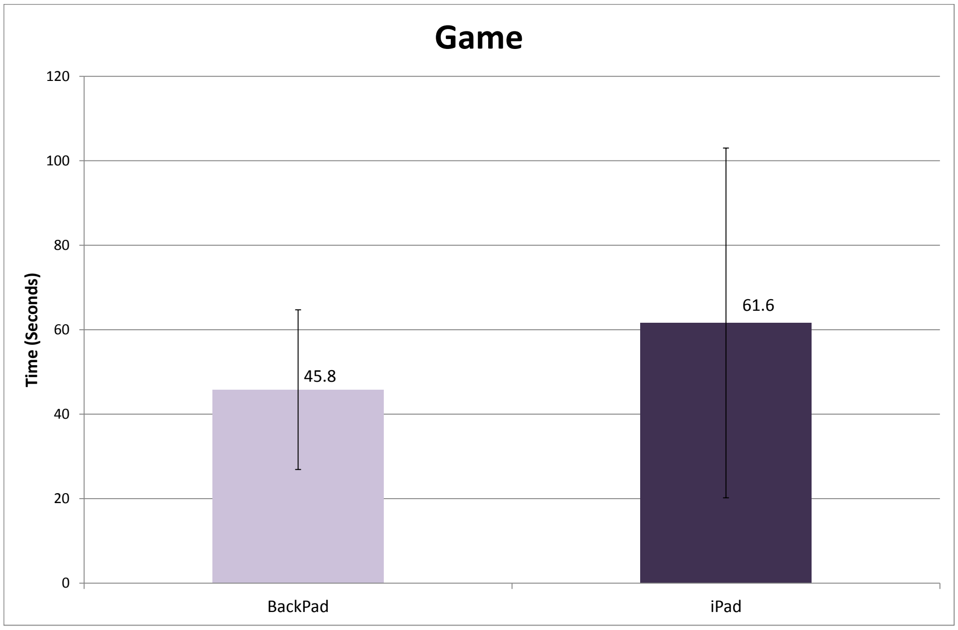


Figure 2.13: game time for each device in the experiment

significant difference in game score between back and front input and front typing is significantly better than back typing. This work is useful regarding designing new PDAs. Future directions include experiments use of external keyboards in any typing tasks, and with BackPads intermediate in size, for example with 13 inch and 15 inch screens.

2.3 Comparing User Performance of an iPad to a 13 BackPad

After two previous experiments, comparing 17 inch BackPad with iPad and comparing front and back input, another experiment was designed with the same functionalities as 17 inch BackPad except the screen, which was a 13 inch screen.

In the last experiment (comparing 17 inch BackPad and iPad) the BackPad did not perform better than the iPad. One of the disadvantages that participants mentioned in the last experiment was about weight of the BackPad. Therefore, we designed this experiment with a 13 inch screen, which was lighter than 17 inch BackPad. In addition, we want to find the best users' performance between the iPad, a 13 inch, a 15 inch and a 17 inch screen size BackPad. There was not enough time for designing another experiment for 15 inch screen and we left that for future work.

After analysing the previous experimental results, it was investigated that typing

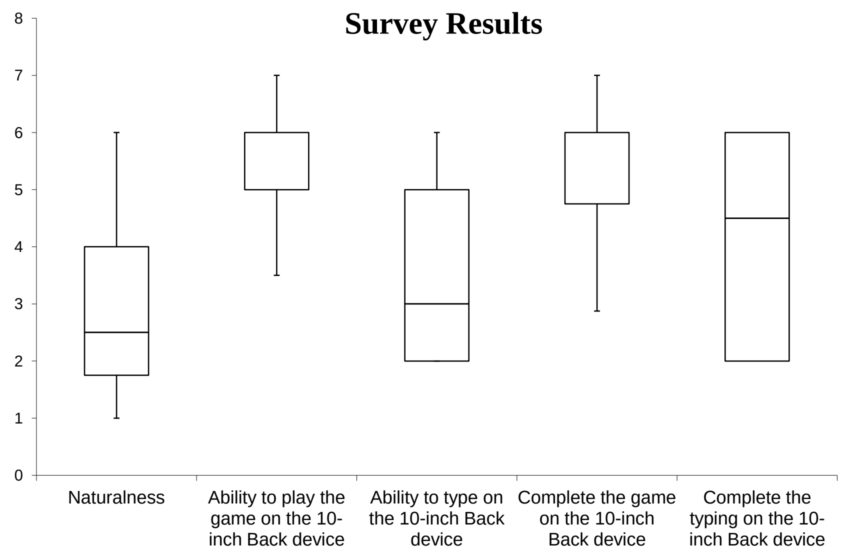


Figure 2.14: Survey results for the experiment
(7- point scale: 1 Strongly Disagree to 7 Strongly Agree)

with a trackpad at the back of a device is difficult and significantly affects on users' performance, but playing a game was not significantly different in the devices. Therefore, we have changed the typing tasks for this experiment to navigation and kept the playing a game task.

2.3.1 Design of Hardware and software

The device's display is a USB Powered Portable Dual 13 inch External Monitor. The monitor is connected to a Dell Latitude laptop with a VGA cable and USB cable for providing power to the monitor. The magic trackpad from apple store [web f] was glued to the back right side of the monitor.

The tasks, game and navigation, were implemented using html5 and uploaded on the author website. For each participant we reload the page and ask him to complete the tasks.

The time users spent to find different spots in game task and street names in navigation task were measured by computer automatic. We used computer to measure the time since it is more accurate than using a spotwatch and it does not involve any human interference. In addition, we record the spots they have click in both tasks to calculate the accuracy of using backpad or touch screen as input and compare them.

2.3.2 Design Tasks

Two tasks were chosen for this experiment: navigation in the map and playing the spot the difference game. To avoid learning affects, the game was designed with two different photos however, the photos were taken from one place with two different angles. (See Figure 2.15 and Figure 2.16)

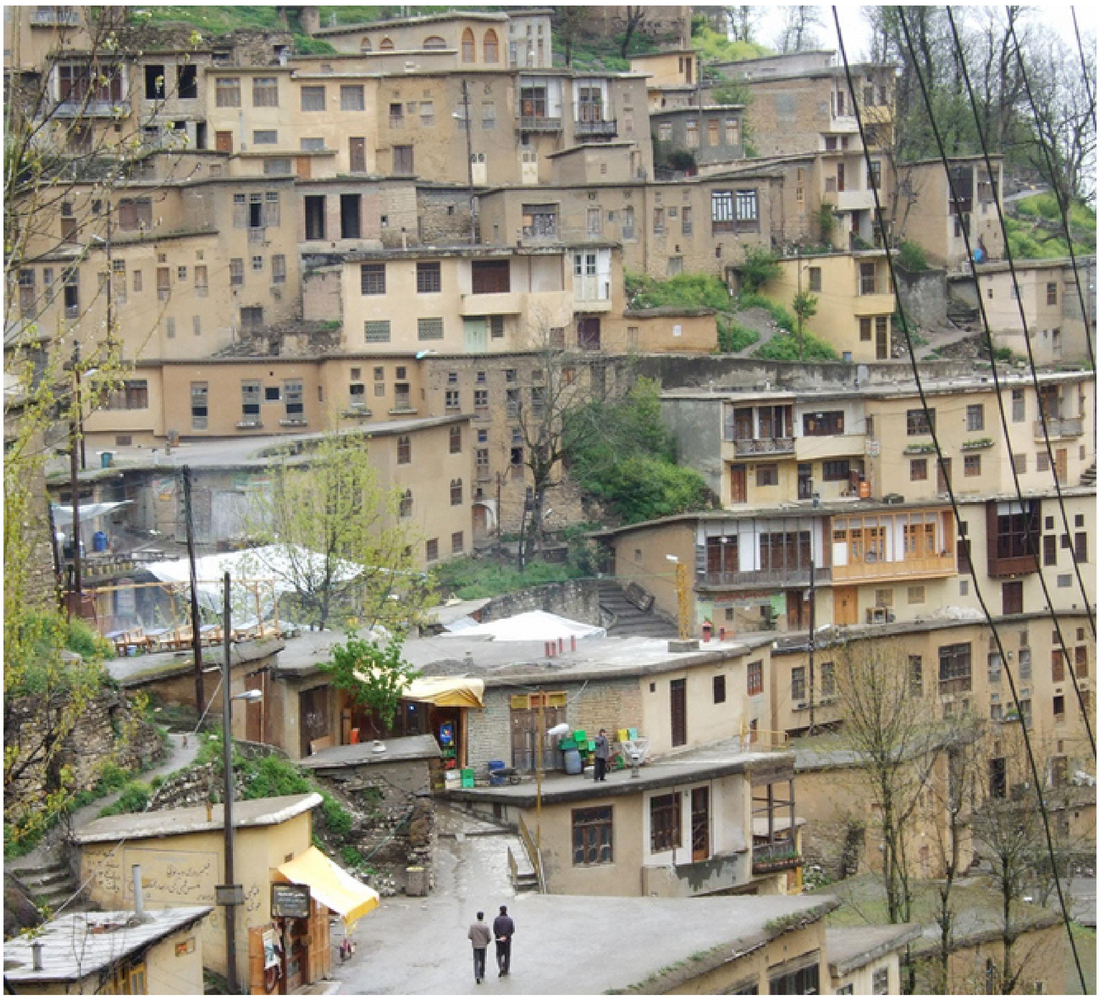


Figure 2.15: The spot the difference game photo one

The photos were 8 cm by 8 cm and we grid them into sixteen 2 cm cells. Ten differences were placed in each photo. Top right and left corners, bottom right and left corners and four differences in the middle of the photos. Five differences were objects that were deleted from the original photos and five others were objects that were added to the original photos.

In addition to the game, navigation in the map was designed as the second task. Two different parts of New Jersey city in the United States were chosen for this task. In the Google map, names of some streets or places are written with the language of

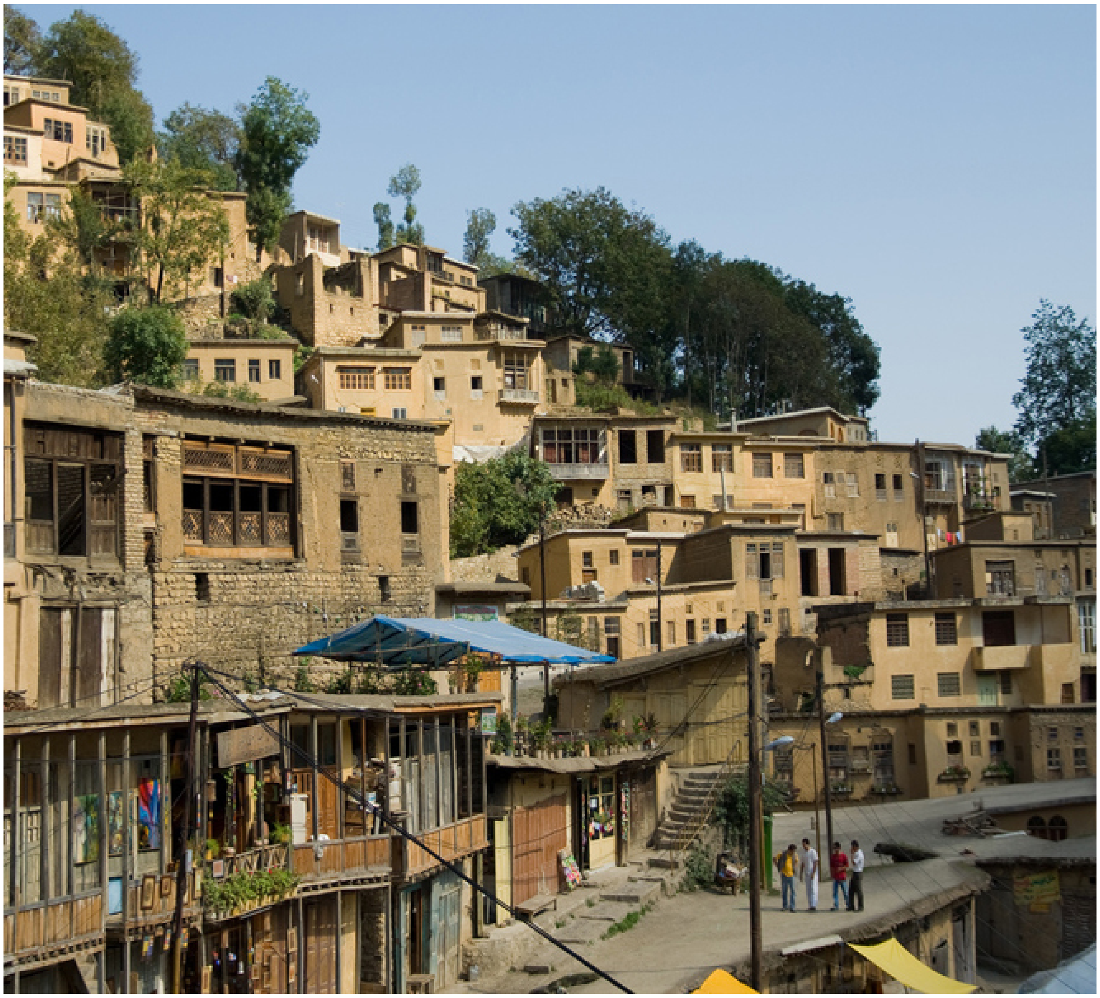


Figure 2.16: The spot the difference game photo two

the country that is placed in.

Since we am running the experiment in Australia, we need all the names in English. Countries such as Australia, England and the United States are appropriate for this task. Since the experiment's participants live in Australia so they might use their knowledge to find the addresses in the maps, but not by scrolling and looking at the maps so we did not chose Australia.

The maps included parks, streets, roads and avenues, highways, suburbs, clubs, universities and sport halls. The font size of the maps names are different considering their importance. New Jersey was chosen and two different places in the city were selected for this task. (See Figure 2.17 and Figure 2.18) Three street names, three suburb names and two park names were given to the participants to find and mark in each map (See Table 2.2 and Table 2.3). Three suburb names were written with font size 10 and the other three street names and park names were written with font size 8.

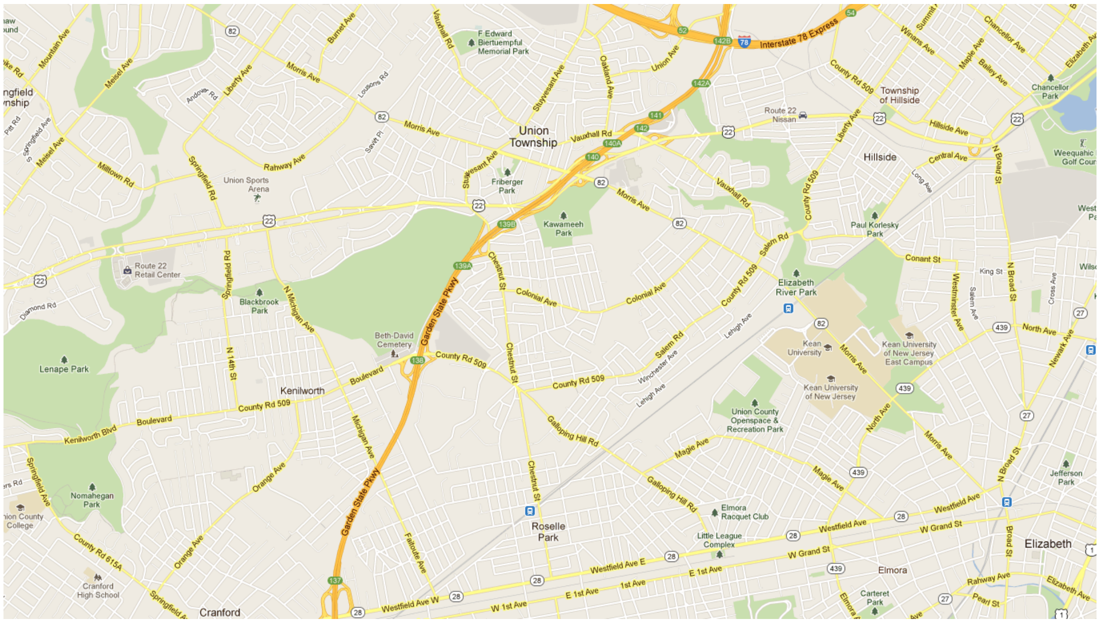


Figure 2.17: The spot the difference game photo two

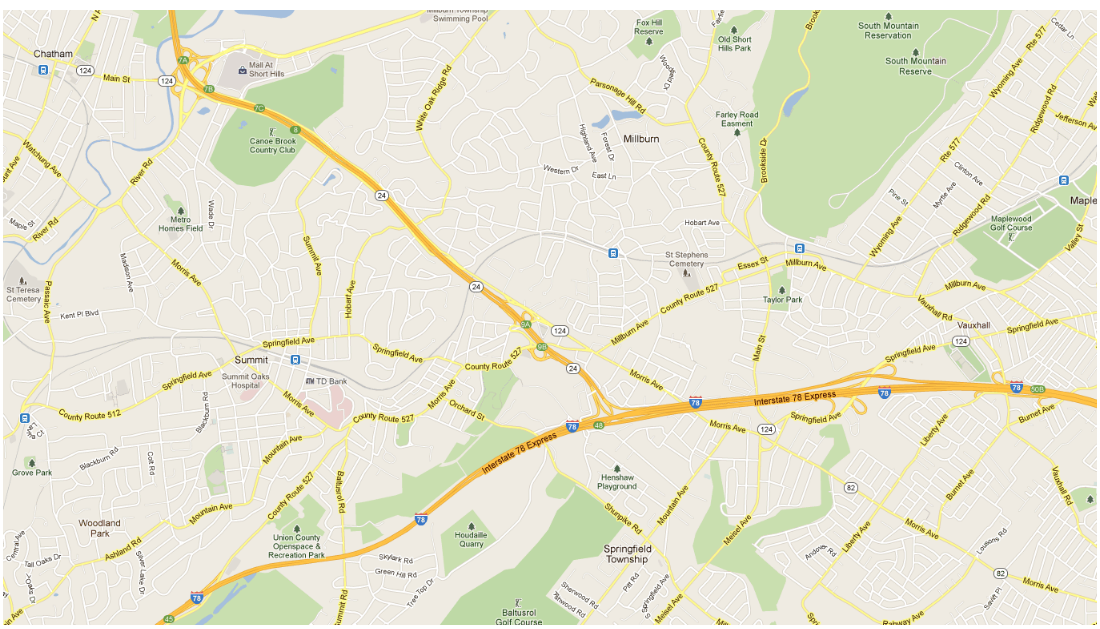


Figure 2.18: The spot the difference game photo two

2.3.3 Memory Test

There is some questions whether users remember a map more when they look at it on a small or a big screen. In Patrick [Patrick et al. 2000] study, large projection displays

Hillside	Rahway Ave	Kawameeh Park
Kenilworth	North Ave	Nomahengan Park
Cranford	Union Ave	

Table 2.2: Street names in the map one

Springfield Township	Orchard St	Fox Hill REserve Park
summit	Watchung Ave	Taylor Park
Woodland Park	White Oak Ridge Rd	

Table 2.3: Street names in the map Two

found more memorable than a standard size desktop.

After the navigation task in this experiment, a memory test was conducted to investigate users' remembering performance. The maps were printed in 12 inch size and were presented with labels on them. We decided to print the maps in a size between the BackPad screen size (13 inch) and the iPad(11 inch). Participants had to mark the street names were in the list they navigated on. The street names list was not available during memory test.

The memory test was examined for one map for each participant. Selecting a map for the memory test depended on the subject's experiment sequence. The participants who navigated on the map number one first and then map number two, did the memory test on the first map and participants with the reverse sequence, did the memory test on the second map. We did not consider any time limitation for answering memory test for participants.

Memory test has been done on 18 participants ranging from 18 to 33 (Mean = 21.1, SD = 3.5). They were all right handed and regular computer users. Subject were informed before the navigation task that it will be a memory test immediately after the navigation task about the places they found on the map.

2.3.4 Participants

By considering the experiment tasks, devices and sequences, we have 8 sequences. We considered 3 participants for each sequence therefore, we need 24 participants to take part in the experiment. Twenty four undergraduate students who mostly study Computer Science, Information Technology and Software Engineering from Comp1710 course in ANU were selected for the experiment.

The user study included 22 male and 2 female participants, ranging from 18 to 33 years of age (Mean = 21.1, SD = 3). Participants were both right handed (23) and left handed (1). The experiment's setting was changed for left handed users. The participants were informed that they could leave the experiment whenever they want.

The experiment's idea and the tasks were first explained for them. In addition, an examiner demonstrated the inputs' (touch screen and trackpad) sensitivity of both devices for the participants. Subjects were asked about their familiarity with iPad before the experiment. They were asked how often they use the iPad daily and how often they use it for playing game and navigation and the questions' answer was a multiple choice, "Often" (more than one hour in a day), "Occasionally" and "Never", Figure 2.19 shows the frequency of all participants iPad usage.

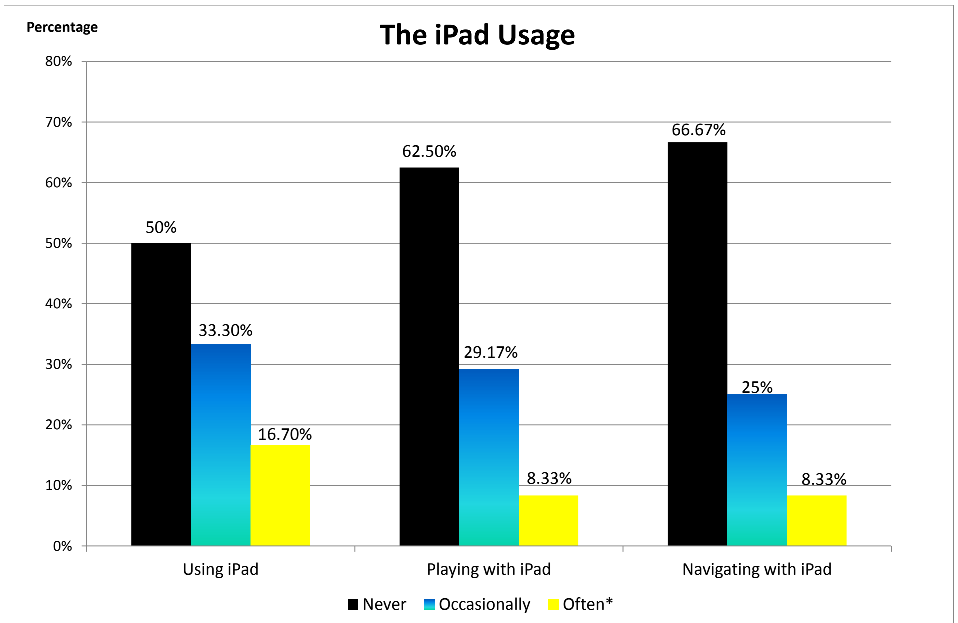


Figure 2.19: The iPad usage among 24 participant subjects in the experiment,
$*$ Often is more than 1 hr/day

2.3.5 Results and Discussion

The data recorded during the game playing and navigating in the experiment were analysed and were presented in this section.

2.3.5.1 Game time

As mentioned in the above section, we had ten different spots for the game task, but because of considering ethic rules, we could not ask participants to find all spots. Therefore, participants left the game at different stages and there were some missing data when we want to run the Paired T-test. We decided to normalize data and fill the spots (time) each participants could not find with depend on his average and the total average of each spot, which shows how much in average finding that spot takes time.

To avoid learning effects during the experiment on each participant, we chose two pictures (with different angles) for the game therefore, we need to compare the pictures to investigate whether there is a significant difference between them or not. As the result, there was no significant difference between images for the game task, T(92) $= -0.5604$, P $= 0.5766$ so we can be sure that the images difference did not affect on the game results.

From users' results, it found that every user found at least four sports. Therefore, we ran a T-test on every users who found four spots in the game and removed the extra spots (after four) time that some users found. Then we ran a T-test on users who found at least five spots, but we removed the users data who found less than five spots and removed the extra spots (after five) some users found. The same test was run for six, seven, eight, nine and ten spots and Table 2.4 shows the results.

The Paired T-test (2-tailed) showed a significant difference in time between playing the game with the BackPad and the iPad, T(239) $= 2.5105$, p-value $= 0.01272$. Fig. 2.20 shows overall mean time for each device. It is clear that playing the game with the 13 BackPad (Mean $= 37.3$, SD $= 43.2$) in the experiment on average participants take significantly less time than playing the game with the iPad (Mean $= 50.1$, SD $= 71.5$).

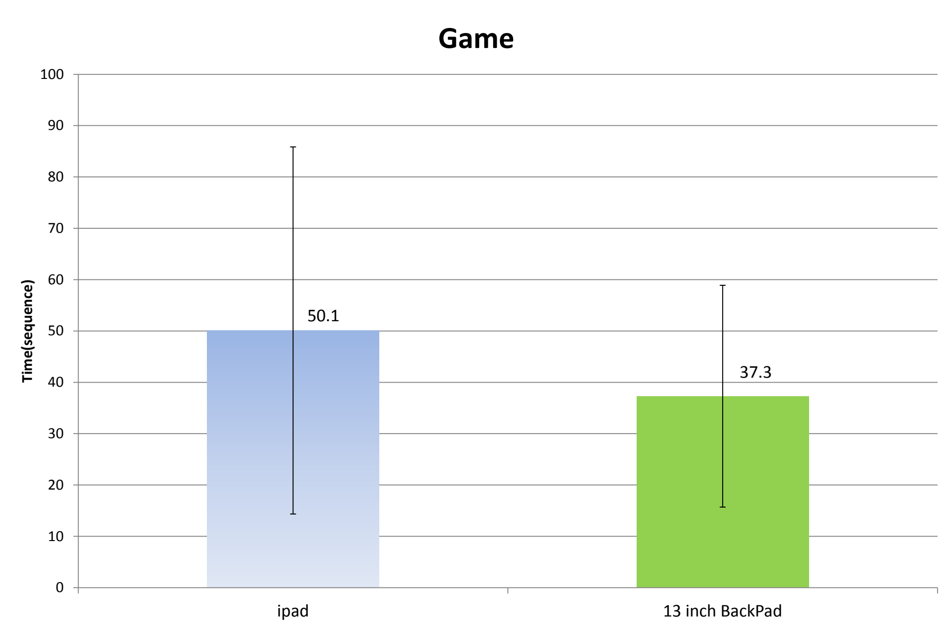


Figure 2.20: Mean playing game time for each device in the experiment

2.3.5.2 Game Spot

In addition to the time users spent on each spots, we record each spot they clicked or touched on the screen. Firstly, we ran a paired T-test on the number of wrong spots

Spots	t-value	df	P-value	Avr BackPad	SD BackPad	Avr iPad	SD iPad	No.users
4	-0.0381	95	0.9697	27.25	28.91	27.46	49.24	24
5	0.1648	114	0.8694	29.70	29.81	30.58	50.75	23
6	-0.0822	137	0.9346	32.01	36.06	32.43	48.92	23
7	-0.6035	132	0.5472	31.54	38.13	34.58	50.05	18
8	-0.9365	127	0.3508	30.89	36.87	36.52	58.63	16
9	0.564	98	0.574	39.91	52.51	36.04	55.44	9
10	-0.3559	39	0.7238	43.25	59.86	45.63	65.02	20

Table 2.4: p-value for number of spots found

users clicked or touched and there was no significant difference between clicking on the 13 inch BackPad and the iPad, t(23) = 0.2594, p-value = 0.7976.

After analysing number of wrong users spots, we calculated the distance between all ten spots and the wrong spot and separated the minimum distance. It assumed that the minimum distance was the one that the user intend to click on or touch. After all, for each user we sum the minimum distances and represent a number, which shows how inaccurate the users clicked. We ran a paired T-test for the users error rate between the 13 inch BackPad (Mean = 4084.545) and the iPad (Mean = 5379.231), t(23) = -0.1008, p-value = 0.9206 and there was no significant difference between them. We divided the total sum of users error rate of the iPad to the 13 inch BackPad.

$$\frac{Sum(ipad-error)}{Sum(13incherror)} = 1.32$$

It can be concluded from the T-test results on number of wrong clicked spots and users error rate that using a trackpad at the back is not less accurate than using touch screen in playing games. In addition, the screen covers by hand while users touched the screen, but if the trackpad placed at the back we could use the whole area of screen.

2.3.5.3 Navigation time

Considering ethic rules, we could not force participants to find all address on the map and they had right to leave whenever they want. Therefore, participants left the game at different stages and there were some missing data when we want to run the Paired T-test. We decided to normalize data and fill the addresses (time) each participants could not find with depend on his average and the total average of each address, which shows how much in average finding that spot takes time.

To avoid learning effects during the experiment on each participant, we chose two maps from same city for the navigation therefore, we need to compare the maps to investigate whether there is a significant difference between them or not. As the result, there was no significant difference between maps for the navigation task, so we can be sure that the maps difference did not affect on the navigation results.

The Paired T-test (2-tailed) showed no significant difference in time between navigating on maps with the BackPad (Mean = 123.2 , SD = 104.3) and the iPad (Mean

= 114.3 , SD = 88.6), T(191)= 0.9653, p-value = 0.3356. Figure 2.21 shows the mean time users spend on navigation task in this experiment.

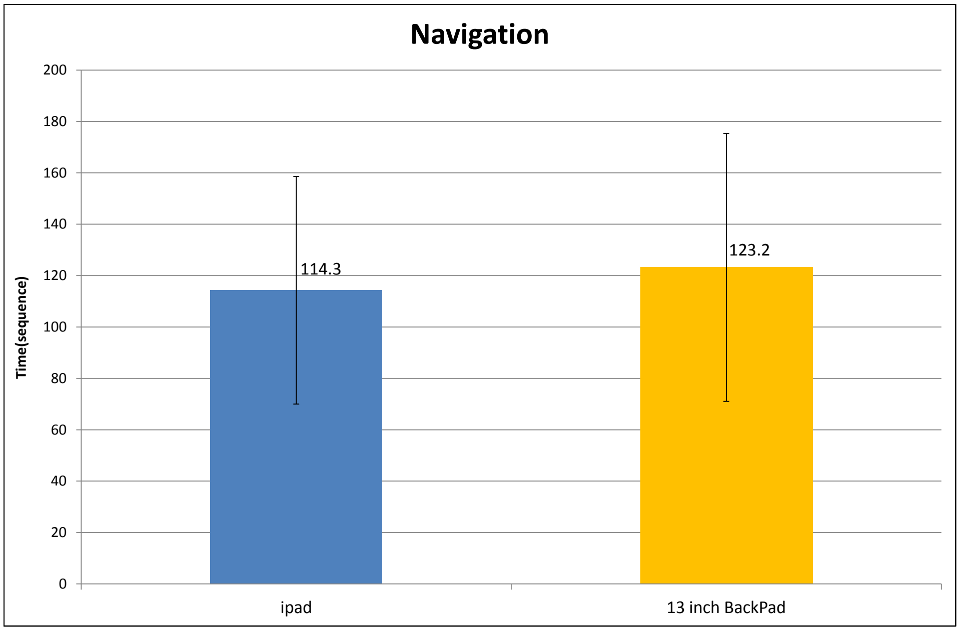


Figure 2.21: Mean navigation time for each device in the experiment

2.3.5.4 Navigation Spot

In addition to the time users spent on each address, we record each spot they clicked or touched on the screen. Firstly, we ran a paired T-test on the number of wrong spots users clicked or touched and there was no significant difference between clicking on the 13 inch BackPad and the iPad, t(23) $= -1.3666$, p-value = 0.185.

After analysing number of wrong users spots, we calculated the distance between all ten spots and the wrong spot and separated the minimum distance. It assumed that the minimum distance was the one that the user intend to click on or touch. After all, for each user we sum the minimum distances and represent a number, which shows how inaccurate the users clicked. We ran a paired T-test for the users error rate between the 13 inch BackPad (Mean = 46727.01) and the iPad (Mean = 122327.4),t(23) = 1.8654, p-value = 0.07493 and there was no significant difference between them. We divided the total sum of users error rate of the iPad to the 13 inch BackPad.

$$\frac{Sum(ipad-error)}{Sum(13incherror)} = 2.62$$

It can be concluded from the T-test results on number of wrong clicked spots and users error rate that using a trackpad at the back is not less accurate than using touch screen in navigation. In addition, the screen covers by hand while users touched the screen, but if the trackpad placed at the back we could use the whole area of screen.

2.3.6 Subjective results

We also surveyed participants to complement the quantitative measures we reported above. The questions in the survey are about "productivity", "satisfactory", "ability to play the game and navigation on the 13 BackPad and the iPad" and "how much they liked to play the game and navigate on the 13 inch BackPad and the iPad". Each question has a 7 point Likert scale from 1-Strongly Disagree to 7-Strongly Agree.

The results of questions from the survey regarding the experiment using the BackPad are represented in Fig. 2.22 which shows the results from the 24 participants. In addition, a question at the end of the survey was asked regarding their comment. One participant suggested to have both touch screen and a trackpad at the back.

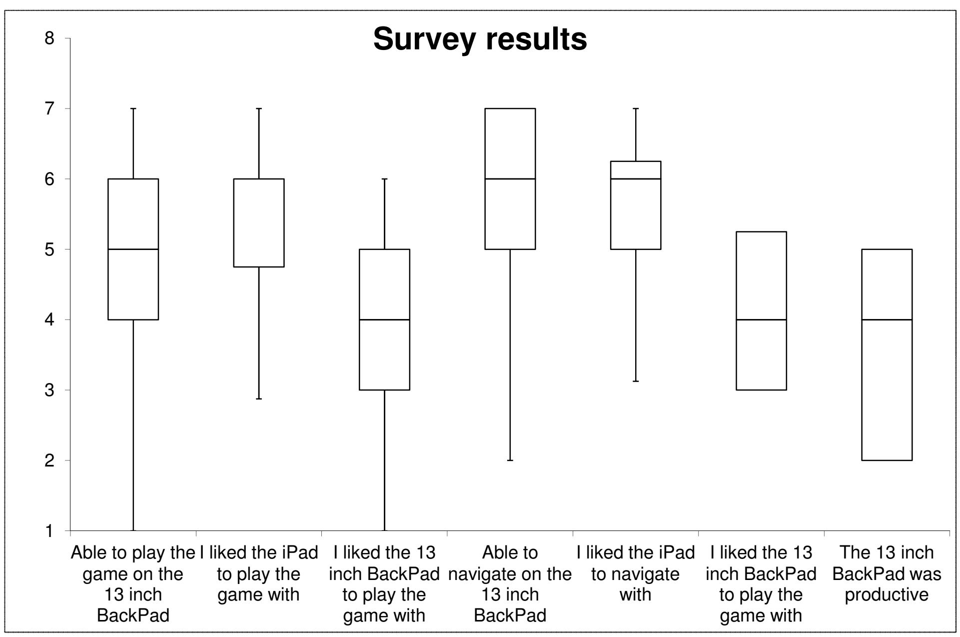


Figure 2.22: Survey results for the experiment
(7- point scale: 1 Strongly Disagree to 7 Strongly Agree)

In addition, we asked them which one of the devices they have liked to play the game and navigate with more. As the results, two participants liked to play with the BackPad and four of them had no preferences and the rest preferred the iPad.

Penalty value	t-value	df	P-value
-0.33	2.2897,	9.142,	0.04737
-0.5	-2.2929	9.383	0.04642
-1	2.2669	10.161	0.04642

Table 2.5: p-value for different penalty values on memory test

2.3.6.1 Memory Test

Memory test was a between group experiment since each participant was tested on one map. Therefore, we did an unpaired t-test on the memory result. Users crossed on the addresses they remembered and if they crossed on a wrong address (, which was not in the address list), a penalty was given to them. We gave them 1/3 for each wrong street and run the T-test and then test that with 1/2 and 1 as well and ran T-test (unpaired) to investigate whether it was significant difference between the iPad and the 13 inch BackPad. Table 2.5 shows the results.

It was significant difference between remembering maps on the iPad and the 13 inch BackPad. The 13 inch BackPad was more memorable than the iPad.

2.3.7 Conclusion

Through the 13 inch BackPad and the iPad experimental results, we concluded that playing the spot the difference game was faster on the 13 inch BackPad than the iPad. However, there was no significant difference in time spend on finding street names between the 13 inch BackPad and the iPad while users navigating on the map.

From the recorded spots users clicked or touched on results, it was investigated that users error rate for clicking at the back of device or touching the screen at the front is not significantly different. We can conclude that the back trackpad was the same accurate as the front touch. In addition, the memory test result shows the 13 inch BackPad was more memorable than the iPad.

Chapter 3

Hand grip strength on a large PDA holding while reading is different from a functional task

How users hold devices is a concern in term of PDA design, as the devices get larger. In future PDA designs, trackpad position could be at the front or back of the device. For example a new large screen PDA is introduced with a trackpad at the back [Rajabiyazdi and Gedeon 2011][Rajabiyazdi and Gedeon 2012a]. It is known that a PDA has to be designed for the wider population [Dunlop and Brewster 2002] so trackpad position could be on either side of the device; right or left, or both.

If a new large iPad were to be manufactured, it will have a heavier weight than the existing iPad due to the increased size of the device. Therefore, possible issues in holding such a heavier device need to be considered. From previous work on grip strength, it seems plausible to consider an iPad with asymmetric weight as a solution so the weight on a weaker hand is reduced. However, in terms of designing asymmetric PDAs, it is necessary to know which side of the iPad should be heavier. The idea of having an asymmetric iPad would be productive if human dominant and non dominant hands have different holding force. If users have similar hand holding force, an iPad with asymmetric weight is not sensible.

The study has two majors intentions: First, measuring maximum and average strength of dominant hand under two conditions; with resting hand on table and without resting hand. Second, finding any relationship between tapping strength with the preferred hand and tapping strength with the non preferred hand. The second experiment is to discover if there is a difference between hand strength in a functional setting, that is, while the user is tapping at the back of a PDA.

The participants' hands' grip force is measured by using two force sensors. We report the hand grip force in grams in our experiment, similar to previous work in the literature.

In addition to PDA design, our studies could be useful in designing prosthetic hands [Annett 1970] [Kimura and Vanderwolf 1970], designing new mobile phone physical body and implementing ergonomic workplaces [Cutler et al. 1997]. The second study especially can be useful in designing new input systems for tablets or

PCs like the RearType prototype [Incel et al. 2002] or for pressure sensitive keyboards [Newman et al. 1984].

The core idea of this experiment is to examine preferred and non preferred hand strength when adult participants hold a device like a PDA. Also in this thesis the difference between tapping strength in dominant and non dominant hand between right handed and left handed participants is measured. We had an equal number of left and right handed users in my experiments to reduce the effects of other factor on the experiments.

Based on the literature, we expect right handed participants to grip more strongly with their right hands, and less strongly with their left. For left handed participants we expect a reduced difference, or possibly no difference. There are no results in the literature for grip strength during tapping, which is significant for a PDA. The lift strength results suggest that we will have similar results for our functional task with a clear difference for right handed participants and a reduced difference for left handed participants.

3.1 Design Hardware

A 15-inch MacBook screen was separated and the screen aluminium case from its back is used for the experiment to simulate a large PDA device with a well designed aspect ratio. We attached two force sensors at the back of the case with a surface sized so that participants put their fingers on them when they hold the device. The total device weighs approximately 1.1 kg due to the size of the sensor surfaces. This is about double the weight of a current model iPad, which is half the size of our 15-inch simulated device.

We tried to simulate situations that users normally encounter when they hold a device like a PDA to read. Two situations are considered for testing; sitting at a table, and so having a hand rest for the forearms and without a hand rest. Participants are asked to read a different paragraph for each test. Also to reduce fatigue effects on the experiment result, a beep sounds every 25 seconds. We mentioned to users to have 2 seconds break when they heard the beep sound and then continue reading.

Participants' hands strength data were collected every five seconds during each 25 second period. The number of 25 second periods depends on the time participants spent on reading the paragraphs. Then we compared participants' hand strength in both tests to see the difference between hand strength with or without having a table used for a hand-rest.

3.2 Design Tasks

We asked participants to complete the tasks in two situations, while they put their elbows on the table and while they hold the device without using table support. In addition, they were asked to move their index finger at the back of the device and follow the given instruction. Each task is discussed with detail in this section.

3.2.1 On table strength test

In this test, subjects asked to fit the chair height to feel comfortable. They sit on the chair in front of a table in the experiment room which they are informed is for a hand-rest, for resting their forearms on. A paragraph with roughly 300 words from a children's story book [Goscinny and Semp 2006] was given to users to read and we measured their hands strength during their reading time. A children's book was used to ensure the text was non-challenging to all participants to avoid the possible effect of text complexity causing stress and possibly greater grip strength as a consequence. We expect that dominant hand grip strength will be more than the non dominant hand when participants use the table as a hand rest.

3.2.2 Off table strength test

In the second test, subjects are again asked to seat themselves comfortably on the chair but this time the table is not available for resting their hands. To avoid learning effects [Lazar et al. 2009] on reading time and skill, a different paragraph from the previous test is chosen. The paragraph was given to users to read has roughly 300 words from the same children's story book [Goscinny and Semp 2006]. We expect dominant hand strength will be more than the non dominant hand when participants do not use the table as a hand rest.

3.2.3 Back fingers movements

We designed this experiment to simulate PDA devices with trackpads at the back. We wanted to examine the difference between positioning a PDA back trackpad at the left or right side of the device. The device used is the same as in the previous experiment.

In this experiment, an instruction is given to participants that they asked to follow. The instruction has 10 tasks to follow. The first five tasks are with the right index finger and the second five tasks are the same as the first tasks but with the left index finger. Tasks are in order; tap with the index finger, move it upward, move it downward, move it to right and move it to left. Participants are asked to act the tasks at the back of device as if it was a touch device, hence the "move it upward" includes a degree of pressure required to create a feeling of friction similar to that experienced in using a touch screen device.

Both right and left handed participants did the ten tasks. Once they hold the device with the dominant hand and did the tasks with their non dominant hand and then they hold it with their non dominant hand and did the tasks with other hand. Their hands strength is measured during the experiment for each task in both situations.

3.3 Participants

Twelve healthy postgraduate students from a local university voluntary participated in the user study. The participants were unpaid and regular computer user. The user study is a between group study which included 6 right handed (4 male and 2 female) and 6 left handed (4 male and 2 female) participants.

Using [McManus et al. 1984] and [Rasmussen and Milner 1977] studies' results we distinguished the participants' handedness based on their writing hand. Participants were Computer Science and IT students ranging from 25 to 37 (Mean = 28, SD = 3) and they all participated in both experiments.

To avoid participants' expectations effect on the experiment results we did not inform them before the experiment that we are measuring their hand strength; they were just advised it was a reading experiment. After the experiments we explained the main aim of the experiment to them.

3.4 Results

Result of the participants performance is shown in this section.

3.4.1 On table results

The Paired T-test (2-tailed) showed a significant difference in hold strength between dominant and non dominant hand, $T(11) = -3.36$, $P = 0.00636$. The maximum hand grip strength belonged to a dominant hand (1608gr). This pattern also follows on the maximum and minimum of average strength (Min=609.0gr, Max=899.1gr) which shows significantly higher strength by the dominant hand during holding. (See Table 3.1)

Table 3.1: Summary of measures of strength for on/off table tests

		First 25 seconds Mean(gr) ± SD (Min-Max)	Second 25 seconds Mean(gr) ± SD (Min-Max)	Third 25 seconds Mean(gr) ± SD (Min-Max)	Forth 25 seconds Mean(gr) ± SD (Min-Max)	Fifth 25 seconds Mean(gr) ± SD (Min-Max)	Sixth 25 seconds Mean(gr) ± SD (Min-Max)
On table	Dominant hand	753.2 ± 372.5 $(1 - 1608)$	740.9 ± 216.7 $(166 - 1065)$	899.1 ± 204.7 $(417 - 1224)$	851.3 ± 147.3 $(551 - 1130)$	892.6 ± 91.9 $(551 - 1002)$	805.1 ± 174.8 $(660 - 986)$
	Nondominant hand	609.0 ± 226.4 $(3 - 960)$	688.1 ± 189.0 $(284 - 1071)$	728.0 ± 191.6 $(391 - 1030)$	772.4 ± 211.3 $(396 - 1189)$	692.8 ± 159.0 $(462 - 885)$	804.5 ± 302.6 $(436 - 1070)$
Off table	Dominant hand	880.7 ± 271.2 $(551 - 1666)$	888.9 ± 278.3 $(546 - 1734)$	980.5 ± 301.8 $(452 - 1778)$	928.1 ± 191.0 $(491 - 1285)$	934.6 ± 202.3 $(651 - 1188)$	846.3 ± 0 $(786 - 918)$
	Nondominant hand	705.5 ± 104.1 $(537 - 1150)$	677 ± 117.7 $(480 - 1057)$	721.9 ± 108.2 $(567 - 1052)$	825.4 ± 110.9 $(514 - 1122)$	761.8 ± 51.6 $(690 - 1002)$	766.5 ± 0 $(665 - 897)$

Fig. 3.1 shows the ratio of average right handed strength to average left handed strength. It is clear that most of left handed ratio is under the line which means they have stronger left hands. Also most right handed are above the line which means they have stronger right hands.

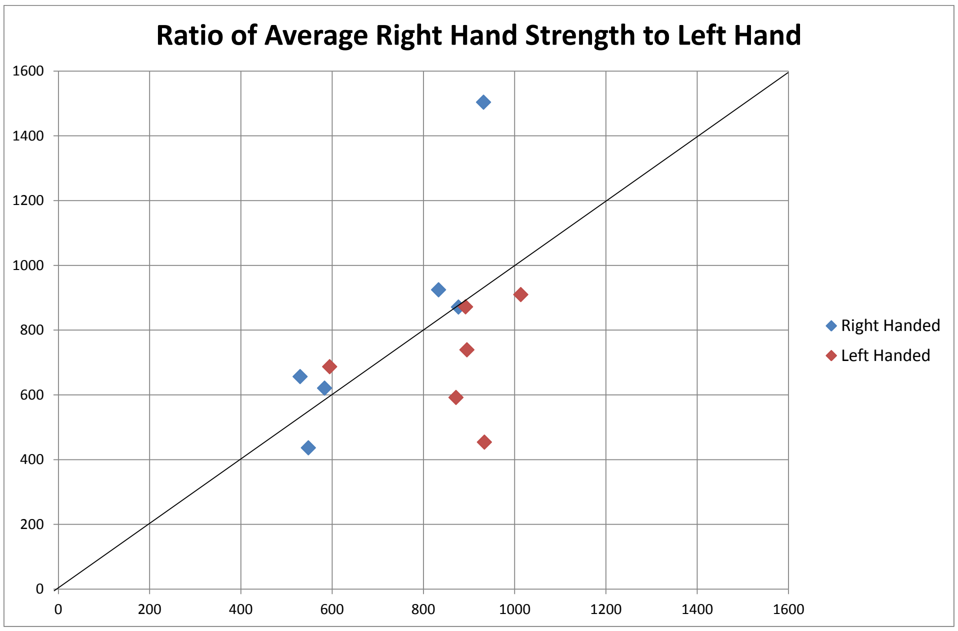


Figure 3.1: Ratio of the average the right hand strength to the left hand for off table test

3.4.2 Off table results

In the off table test the Paired T-test (2-tailed) showed a significant difference in grip strength between dominant and non dominant hand, T(11) = 2.38, P = 0.0362. In addition to T-test results the maximum of average strength in all 25 seconds periods among dominant and non dominant hands belonged to a dominant hand (980.4 gr) and the minimum average strength (677 gr) was for a non dominant hand which was as expected. Also the maximum hand strength is in the group of dominant hands and is 1778 gr.

Fig. 3.2 shows the ratio of right hands' average grip strength to left hands' average strength in the off table test. Similarly to the on table test, the off table test results shows most right hand strengths average above the line and left handed strengths under the line. This is evidence for stronger right hands for right handed and stronger left hands for left handed users.

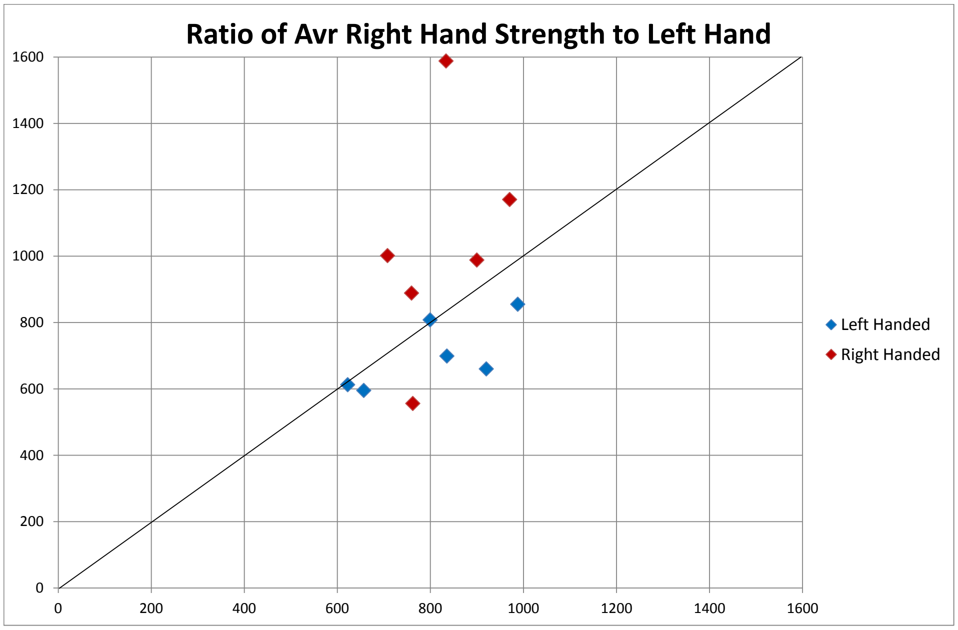


Figure 3.2: Ratio of the average the right hand strength to the left hand for on table test

3.4.3 Comparing on and off table results

We ran the Paired T-test (2-tailed) on the results of hand strength from the first and second tests. There is a significant difference between holding a device with having a hand rest and without a hand rest with the dominant hand, T(5) = -4.8129, P = 0.004828. But there is no difference between non dominant hand strength while holding a device on or off table, T(5) = -1.3217, P = 0.2435.

It is also clear that maximum average (980.5 gr) dominant hand strength is higher in the off table test than in the on table test (Mean=899.1 gr).

3.4.4 Back fingers movement results

1) Dominant hand vs. non dominant hand:

We compared the tasks done with the dominant hand versus non dominant hand. There was no significant difference between dominant and non dominant hand in these tasks. It is interesting that by placing a (simulated) PDA trackpad at the back, no significant difference was found in users' grip strength between positioning it at the left side or right side for both left and right-handed users. Table 3.2 shows the results of the Paired T-test (2-tailed).

Table 3.2: T-test, mean, SD, Min and Max summary second experiment results between tasks with right hand and tasks with left hand

	P-Value	T	Right Mean(gr) $\pm$ SD	Left Mean(gr) $\pm$ SD
Tap	$0.681 > 0.05$	0.4247	675.8 ± 407.2	616.2 ± 350.3
Move Up	$0.677 > 0.05$	0.4312	690.6 ± 344.3	585.1 ± 309.7
Move Down	$0.739 > 0.05$	0.3431	649.5 ± 348.9	563.7 ± 242.1
Move to Right	$0.823 > 0.05$	-0.231	547.8 ± 266.2	562.2 ± 275.3
Move to Left	$0.999 > 0.05$	0.0015	566.7 ± 311.8	535.1 ± 307.4

Table 3.3: Summary of T-test results on second experiment tasks

	P-Value	T	Mean (gr)$\pm$SD dominant hand Mean (gr)$\pm$SD nondominant hand	Min-Max (gr)$\pm$SD dominant hand Min-Max (gr)$\pm$SD nondominant hand
Tap	$0.276 > 0.05$	1.160	682.6 ± 372.6	$17 - 810$
			602.7 ± 230.0	$294 - 959$
Move Up	$0.886 > 0.05$	-0.148	643.3 ± 289.6	$49 - 827$
			626.6 ± 274.1	$283 - 1134$
Move Down	$0.837 > 0.05$	-0.212	594.8 ± 337.0	$57 - 1007$
			615.3 ± 232.4	$275 - 953$
Move to Right	$0.423 > 0.05$	0.840	551.0 ± 283.0	$19 - 589$
			560.2 ± 129.8	$345 - 732$
Move to Left	$0.581 > 0.05$	0.573	584.6 ± 302.3	$72 - 659$
			512.3 ± 161.1	$201 - 639$

2) Right tasks vs left tasks There is no significant difference between right and left tap, move right index finger to up/down and move left index finger to up/down and move right index finger to right/left and move left index finger to right/left. This result came from running the T-test on tasks with right index finger and tasks with left index finger (See Table 3.3 for the T-test results).

3) Right handed vs left handed We analysed the second experiment results to examine the difference between right handed and left handed participants in both tasks type; tasks were done with right index finger and tasks were done with left index finger.

a) Tasks with the right index finger

The Paired T-test (2-paired) results for tapping with right index finger does not show any significant difference between right handed and left handed users, P-value = 0.540. From this result it is clear that position of a back trackpad on a PDA does not change either left or right handed users' grip strength.

Also there is no significant difference between right and left handed participants' grip strength which emphasizes the above result. Fig. 3.3 shows the average summary of tasks with right index finger.

b) Tasks with the left index finger

For the left tasks we found the same results as were achieved for the right side tasks. There is no significant difference between left and right handed grip strength on tasks which used the left index finger. The Paired T-test results for tapping (T(4) = -0.003, P-value = 0.998), moving the index finger up (T(4) = -0.311, P-value = 0.771),

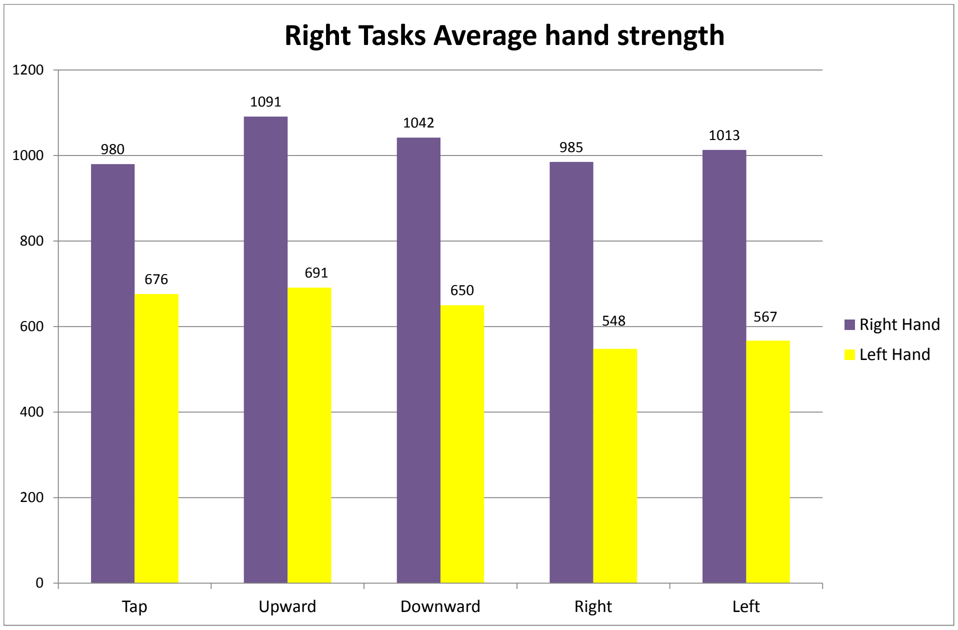


Figure 3.3: summary of tasks with the right index finger

moving the index finger down (T(4) = 0.628, P-value = 0.564), moving the index finger to right (T(4) = -0.119, P-value = 0.911) and moving the index finger to left (T(4) = 1.066, P-value = 0.346) verifies the right tasks' results, none are significant, which is an unexpected result. (See Figure 3.4)

3.5 Discussion and Conclusion

We presented two user studies that simulated human hand grip behaviour while holding a PDA. The first study was done with two different conditions; having a hand rest using a table and without having any hand rest. These tests compared dominant and non dominant hand grip strength while users hold a 15 inch simulated PDA device. From the objective measures, we demonstrated that dominant hand strength is significantly higher than non dominant hand while users hold the device in both conditions. This was an expected result and in line with previous related literature.

The difference between hand performance could have physical reasons. Several studies show the dominant and non dominant hand differs in the motor system. A lower threshold for hand muscles activation was found in dominant hands [Triggs et al. 1994]. In addition, a larger area was found in the dominant motor cortex and similarly a larger distal forelimb for the dominant hand than the non dominant hand was

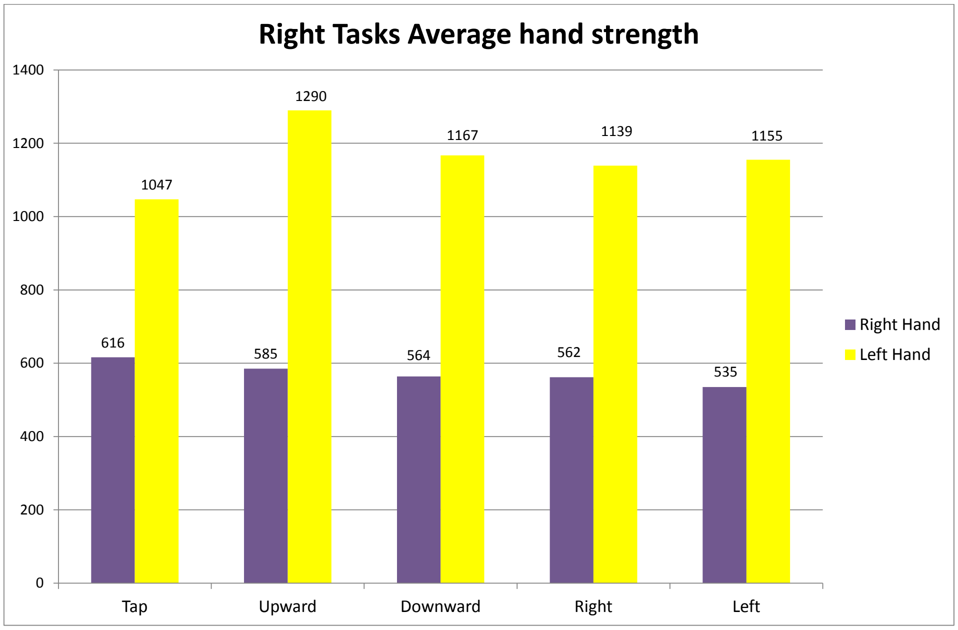


Figure 3.4: Average summary of tasks with the left index finger

found by Nudo et al. [Nudo et al. 1992]. These findings in dominant and non dominant hand confirm that dominant hands are generally stronger, and exert stronger grip during holding.

The second experiment examined the difference between hand grip strength while a user is tapping their index finger or moving the index finger at the back of a PDA. We found no significant difference between the force of dominant and non dominant hands for tapping at the back of the device and moving the index finger up, down, to right and left at the back of the device.

Also the second experiment measured the difference between right handed and left handed users in the tasks with their right index finger. After analysing the data, no significant difference was found between the right and the left handed users' right index finger strength in completing the right tasks. The same results also were found for tasks with left index fingers. As mentioned before all tasks were done with index fingers at the back of the device. Using an index finger at the back is not a familiar task for participants. So it is possible that the lack of significant difference between the right and the left handed users' index finger strength could be due to users' unfamiliarity with tasks at the back, or that the task relates to some finger activities done by both hands, which we can differentiate in future work.

Our results have indications for the physical design and interface design for large

PDAs. In particular, previous work suggests asymmetrical weights would be ok (and may be caused by battery weight for example), and single trackpads under the dominant hand. Meanwhile our result on a simulated PDA in a functional task suggests symmetrical weighting and that dual trackpads used by both hands interchangeably are more suitable.

It is clear that the use of our functional setting simulating the kinds of actions which will be performed on a device provided quite different results from the previous literature and our results for simple holding of the device while reading.

Chapter 4

Conclusion

A new device, a 17 inch BackPad has been introduced. The device has a 17 inch screen and a trackpad at the back. The iPad screen size is 10 inch wide and it has a front touch screen input. The devices, 17 inch BackPad and iPad have two different factors to compare, screen size and input.

Three tests are needed to complete this comparison, i) comparing 17 inch screen versus 10 inch screen, ii) comparing front input versus back input and iii) comparing the 17 inch BackPad and the iPad. The screen size comparison test between 56 inch, 13 inch and 2 inch screens was done before previously Reeves et al.[Reeves et al. 1999]. The authors found the greatest skin conductance, highest level of arousal and highest heart rate that the larger screen was best. We can reasonably assume that this holds for 17 inch over the 10 inch, which was supported by our qualitative results.

The other two tests for comparing the front and the back input and comparing the 17 inch BackPad and the iPad are done in this thesis. The front and back experiment is done with two different tasks, typing and playing game. A significant difference was found between front and back typing. Typing at the front was faster than typing at the back. But there is no significant difference between game playing in the 10 inch BackPad and the iPad.

Also, comparison between the 17 inch BackPad and the iPad is completed by two tasks. From 16 participants data results, no significant difference were discovered while users played the game. On the other hand, typing was faster on the iPad than the 17 inch BackPad. The 17 inch BackPad is not comfortable for typing, but from participants' comments, the 17 inch BackPad was more desirable for playing the game.

It should be mentioned that since we wanted to examine the same tasks in both comparisons, comparing the 17 inch BackPad with the iPad and comparing front touch screen iPad and the 10 inch, we did two separate experiments to avoid learning and fatigue [Lazar et al. 2009].

From objective and subjective results on our 10 inch Back and the iPad with a front touch screen, we demonstrated the same results as the first experiment. There is no significant difference in game score between back and front input and front typing is significantly better than back typing. This work is useful regarding designing new PDAs.

Users who participated in the first experiment left some comments about the 17 inch screen weight. They said "The device was a bit heavy to carry or hold for a long amount of time”. In addition, we thought that using a mobile device with a 17 inch screen might be not comfortable enough. Therefore, we redesigned our device with a 13 inch screen and tested that to investigate if users performance improves or not.

Through the 13 inch BackPad and the iPad experimental results, we concluded that playing the spot the difference game was faster on the 13 inch BackPad than the iPad. However, there was no significant difference in time spent on finding street names between the 13 inch BackPad and the iPad while users navigated on the map.

From the recorded spots users clicked or touched on results, it was found that users error rate for clicking at the back of device or touching the screen at the front is not significantly different. We can conclude that the back trackpad had the same accuracy as the front touch. In addition, the memory test result shows the 13 inch BackPad was more memorable than the iPad.

We did three experiment on right handed participants and to make sure the results would not change if we would do that on left handed, we have designed another experiment. In addition, the trackpad at the right side of the BackPads made the right side a bit heavier and we did the experiment to investigate whether users hand grip is likely to affect our results or not.

We presented two user studies that simulated human hand grip behaviour while holding a PDA. The first study was done with two different conditions, having a hand rest using a table and without having any hand rest. These tests compared dominant and non dominant hand grip strength while users hold a 15 inch simulated PDA device. From the objective measures, we demonstrated that dominant hand strength is significantly higher than non dominant hand while users hold the device in both conditions. This was an expected result and in line with previous related literature.

The second experiment examined the difference between hand grip strength while a user is tapping their index finger or moving the index finger at the back of a PDA. We found no significant difference between the force of dominant and non dominant hands for tapping at the back of the device and moving the index finger up, down, to right and left at the back of the device.

Also the second experiment measured the difference between right handed and left handed users in the tasks with their right index finger. After analysing the data, no significant difference was found between the right and the left handed users’ right index finger strength in completing the right tasks. The same results also were found for tasks with left index fingers. These results were not expected from the literature.

Our results have indications for the physical design and interface design for large PDAs. In particular, previous work suggests asymmetrical weights would be ok (and may be caused by battery weight for example), and single trackpads under the dominant hand. Meanwhile our result on a simulated PDA in a functional task suggests symmetrical weighting and that dual trackpads used by both hands interchangeably are more suitable.

It is clear that the use of our functional setting simulating the kinds of actions which will be performed on a device provided quite different results from the previous literature and our results for simple holding of the device while reading.

Chapter 5

Future Work

In this thesis, we have designed a tablet with a trackpad at the back and a big screen size. We have tested a 17 and a 13 inch screen and left the other screen sizes for future work. For finding the right size of the screen of our device, we need to examine a number of unique tasks on different screen sizes and compare their results. Testing the BackPads with other tasks that are popular on mobile devices such as web browsing, using calculator, playing music and so on could improve the BackPad design.

In addition, we attached trackpad at the back of the devices and users could see their fingers movement while which makes working with that a bit hard.

we can compare our tablet with pinchpad [Wolf et al. 2012] through some user experiments.

Our ergonomic experiment shows no significant difference in hand strength between right and left trackpad position while a PDA has a symmetric weight spread in the device. Each trackpad added at the back of device, creates an extra weight to be added to the PDA weight.

With a single added trackpad, a PDA could have an asymmetric weight with a heavier side. A further study should examine the difference between right and left hand strength using a PDA with asymmetrical weight. That study has to be able to show if it is possible to have an extra weight on one PDA side without adverse effects on the tasks performance.

We only measured the hands' grip strength for using a back trackpad. We found that in the functional task setting there was no difference related to hand dominance. An experiment to track accuracy at the back should be done next to determine which of our possible explanations is correct. We note that since large PDA devices of the size we envision and with a weight we consider sensible are not yet actually available (unlike the much heavier tablet devices), so we are limited to simulating single properties at a time.

Appendix A

A.1 Comparing BackPad and iPad, Typing paragraphs

A.1.1 iPad

Today we will go and play golf on a small golf course next to the big souvenir shop. There are eighteen holes and you have to get the balls right into the holes with as few strokes as possible.

A.1.2 BackPad

I am not lending him my whistle. It is a family heirloom said Rufus and that was that. We decided that Cut would tell him when he wanted the whistle blown and then Rufus would blow it for him.

A.2 Hand grip strength on a large PDA holding while reading, reading paragraphs

A.2.1 On table reading

Today we thought wed go and play miniature golf on the miniature golf course next to the souvenir shop. Miniature golf is really great! This is how you play it: there are eighteen holes and they give you balls and golf clubs and you have to get the balls into the holes with as few strokes as possible. And you have to go past little castles and little rivers and zigzag paths and tiny hills to get to the holes. Its fantastic. The only easy hole is the first one. The trouble is, the miniature golf man wont let us play unless theres a grown-up with us. So me and Ben and Freddy and Monty (Monty isnt half daft!) and Ian and Justin and Christopher, who are all staying in our hotel, went to ask Dad to play miniature golf with us.

No, said Dad. He was reading his paper on the beach. Oh, come on! Be a sport! said Ben.

Oh, come on! Oh, come on! shouted the others, and I started to cry and I said if I couldnt play miniature golf I was going to get in one of those pedal boats they have on the boating lake and go a long, long way away and theyd never see me again. You cant, said Monty (Monty isnt half daft!), you have to have a grown-up with you to hire a pedal boat.

Huh! said Christopher. Christopher gets on my nerves, because hes always showing off. I dont need any pedal boat; I can go a long, long way just doing the crawl! We were all standing round Dad, arguing, and then Dad screwed up his paper and threw it on the sand and he said, All right, all right, Ill take you to play miniature golf.

A.2.2 Off table reading

My dad is the best dad in the world, and I told him so and I hugged him. When the miniature golf man saw us coming he didnt really want to let us play, but we started shouting, Oh, come on! Oh, come on! and then the miniature golf man said all right, but Dad was to keep a sharp eye on us. We started at the first hole, which is dead easy, and Dad, who knows ever so many things, showed us the right way to hold a club. I know how already! said Christopher, and he wanted to start playing, but Justin asked why he should go first. We ought to go in alphabetical order, like at school when the teacher asks questions, said Ben, but I didnt think that was right, because Nicholas is a long way down the alphabet and thats OK at school but it isnt fair in miniature golf. And then the miniature golf man told Dad wed better start, because there were other people waiting to play miniature golf.

Monty can start, because hes the best behaved, said Dad. And Monty came up and hit the ball ever so hard with the club, and the ball went up in the air and it went over the fence and it went smash! right into a car that was out in the road. Monty started to cry and Dad went to look for the ball. Dad was some time coming back because there was a man in the car in the road, and the man got out of the car and he started talking to Dad and waving his arms about in the air, and some people came along to watch and they were all laughing.

We wanted to go on playing, but Monty was sitting on the hole and crying, and saying he wouldnt get up till he had his ball back and he hated us all. Then Dad came back with the ball. He didnt look too pleased.

A.3 Tapping instruction

Imagine there is a trackpad at the back of the device you have hold. Now follow these instructions:

- Tap your right index finger twice.
- Tap your right index finger up twice.
- Move your right index finger down twice.
- Move your right index finger to right twice.
- Move your right index finger to left twice.

- Tap your left index finger twice.
- Move your left index finger up twice.
- Move your left index finger down twice.
- Move your left index finger to right twice.
- Move your left index finger to left twice.

Appendix B

B.1 Survey questions for experiment comparing an iPad to a 17 inch BackPad and the experiment comparing front and back touch

User Study Questionnaire Thank you for taking the time to fill in this questionnaire. Please respond as truthfully as possible, as criticism is appreciated as much as positive feedback.

1 Personal Details

1. Name:

2. Age:

3. Sex:

   male female

4. Occupation (if you are a student, please specify your major):

5. How often do you use an iPad?

   Never Occasionally Often (at least 1 hours a day)

6. How often do you play games with your iPad?
   Never Occasionally Often (at least 1 hours a day)

7. How often do you use your iPad for writing documents?
   Never Occasionally Often (at least 1 hours a day)

2 Presence Questions

Using big screen iPad:

1) It was natural to use this big screen iPad.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

2) I felt intuitive to use this big screen iPad.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

3) It was easy to learn to use this big screen iPad.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

4) I was able to play game on big screen iPad.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

5) I was able to type on big screen iPad.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

6) I could effectively complete the playing game.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

7) I could effectively complete the typing experiment.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

8) I believe I could become productive using this big screen iPad.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

9) Overall, I am satisfied with this big screen iPad.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

3 Open Ended Questions

1. Please rank the big screen iPad you used in the experiment based on your experience (the best one goes first).

2. In what way do you feel the big screen iPad either enhanced, or detracted the performance of the tasks?

3. Do you have any other comments about the control methods or anything related to them?

B.2 Survey questions for experiment comparing an iPad to a 13 inch BackPad

User Study Questionnaire Thank you for taking the time to fill in this questionnaire. Please respond as truthfully as possible, as criticism is appreciated as much as positive feedback.

1 Personal Details

1. Name:

2. Age:

3. Sex:

   male female

4. Occupation (if you are a student, please specify your major):

5. How often do you use an iPad?

   Never Occasionally Often (at least 1 hours a day)

6. How often do you play games with your iPad?
   Never Occasionally Often (at least 1 hours a day)

7. How often do you use your iPad for Navigation?
   Never Occasionally Often (at least 1 hours a day)

8. Have you ever lived in New York before?
   Yes (Please specify how long) No

2 Presence Questions

Spot the Difference Game:

1) I was able to play on 13 inch screen device.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

2) 2. I liked to use iPad for this game Ive played with:
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

3) 3. I liked to use the 13 inch screen device for this game Ive played with:
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

4) Which device do you prefer more to play this game with?
iPad 13 inch screen No preference
Navigation in the city:
5) I was able to navigate on 13 inch screen device.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

6) I liked to use the 13 screen for the navigation task:
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

7) I liked to use the 13 inch screen device for the navigation task:
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

8) Which device do you prefer more to use for navigation?
iPad 13 inch screen
General

9) I believe I could become productive using this 13 inch screen device.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

10) Overall, I am satisfied with this 13 inch screen device.
1 2 3 4 5 6 7
Strongly Disagree Strongly Agree

3 Open Ended Questions

1) In what way do you feel the 13 inch screen device either enhanced, or detracted for the performance of the tasks?

2) Do you have any other comments about the control methods or anything related to them?

Bibliography

27 inch ipad2. (p. 14)

Amazon, kindle. (p. 4)

Bamboo connect. (p. 22)

Best netbooks. (p. 4)

Big bang 4 in a row. (p. 23)

magic trackpad. (p. 34)

Physical and motor skills. (p. 23)

Schoolfreeware. (p. 23)

ANNETT, M. 1970. A classification of hand preference by association analysis. *British journal of psychology 61*, 3, 303–321. (pp. 15, 16, 45)

BERGMAN, E. 2000. *Information appliances and beyond: interaction design for consumer products*. Morgan Kaufmann. (pp. 5, 21)

BRACKEN, C. AND PETTEY, G. 2007. It is really a smaller (and smaller) world: presence and small screens. In *Proceedings of the 10th International Workshop on Presence.(Barcelona, Spain)* (2007), pp. 283–290. (pp. 1, 10)

BREWSTER, S. 2002. Overcoming the lack of screen space on mobile computers. *Personal and Ubiquitous Computing 6*, 3, 188–205. (pp. 1, 9, 10)

BUXTON, W., HILL, R., AND ROWLEY, P. 1985. Issues and techniques in touch-sensitive tablet input. In *ACM SIGGRAPH Computer Graphics*, Volume 19 (1985), pp. 215–224. ACM. (pp. 13, 21)

CHURCHILL, D. AND HEDBERG, J. 2008. Learning object design considerations for small-screen handheld devices. *Computers & Education 50*, 3, 881–893. (p. 2)

CUTLER, L., FRÖHLICH, B., AND HANRAHAN, P. 1997. Two-handed direct manipulation on the responsive workbench. In *Proceedings of the 1997 symposium on Interactive 3D graphics* (1997), pp. 107–114. ACM. (pp. 17, 45)

DUNLOP, M. AND BREWSTER, S. 2002. The challenge of mobile devices for human computer interaction. *Personal and Ubiquitous Computing 6*, 4, 235–236. (pp. 2, 45)

FINDLATER, L. AND MCGRENERE, J. 2008. Impact of screen size on performance, awareness, and user satisfaction with adaptive graphical user interfaces. In *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems* (2008), pp. 1247–1256. ACM. (pp. 10, 11)

FLESCH, R. 1948. A new readability yardstick. *Journal of applied psychology 32*, 3, 221. (pp. 23, 30)

GLEESON, M., STANGER, N., AND FERGUSON, E. 2004. Design strategies for gui items with touch screen based information systems: assessing the ability of a touch screen overlay as a selection device. (pp. 12, 13, 21)

GONG, J. AND TARASEWICH, P. 2004. Guidelines for handheld mobile device interface design. In *Proceedings of DSI 2004 Annual Meeting* (2004), pp. 3751–3756. Citeseer. (p. 2)

GOSCINNY, R. AND SEMP, J. 2006. *Nicolas on Vacation*. Phaidon Press. (pp. 29, 47)

HAN, J., ZHANG, B., LIU, J., AND CHEN, X. 2010. The comparative study of mainstream e-book readers. In *Computer Science and Information Technology (ICCSIT), 2010 3rd IEEE International Conference on*, Volume 8 (2010), pp. 461–464. IEEE. (p. 3)

HOGGAN, E., BREWSTER, S., AND JOHNSTON, J. 2008. Investigating the effectiveness of tactile feedback for mobile touchscreens. In *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems* (2008), pp. 1573–1582. ACM. (pp. 5, 6, 21)

INCEL, N., CECELI, E., DURUKAN, P., ERDEM, H., YORGANCIOGLU, Z., ET AL. 2002. Grip strength: effect of hand dominance. *Singapore medical journal 43*, 5, 234–237. (pp. 17, 46)

KAMBA, T., ELSON, S., HARPOLD, T., STAMPER, T., AND SUKAVIRIYA, P. 1996. Using small screen space more efficiently. In *Proceedings of the SIGCHI conference on Human factors in computing systems: common ground* (1996), pp. 383–390. Citeseer. (p. 9)

KÄRKKÄINEN, L. AND LAARNI, J. 2002. Designing for small display screens. In *Proceedings of the second Nordic conference on Human-computer interaction* (2002), pp. 227–230. ACM. (pp. 5, 21)

KIMURA, D. AND VANDERWOLF, C. 1970. The relation between hand preference and the performance of individual finger movements by left and right hands. *Brain: A Journal of Neurology; Brain: A Journal of Neurology*. (pp. 17, 45)

KINGERY, D. AND FURUTA, R. 1997. Skimming electronic newspaper headlines: A study of typeface, point size, screen resolution, and monitor size. *Information processing & management 33*, 5, 685–696. (p. 11)

LAZAR, J., FENG, J., AND HOCHHEISER, H. 2009. *Research methods in human-computer interaction*. John Wiley & Sons Inc. (pp. 29, 47, 57)

LEE, T. 2004. Static lifting strengths at different exertion heights. *International journal of industrial ergonomics 34*, 4, 263–269. (p. 18)

MCMANUS, I. ET AL. 1984. Genetics of handedness in relation to language disorder. *Advances in neurology 42*, 125–138. (p. 48)

MORAR, S. AND KYRITSIS, M. 2011. Mobile gaming: Investigating the effects of screen and keyboard size on game playablity and interaction. *Journal of Intelligent Systems 15*, 1-4, 129–152. (p. 8)

NALCACI, E., KALAYCIOĞLU, C., ÇIÇEK, M., AND GENÇ, Y. 2001. The relationship between handedness and fine motor performance. *Cortex 37*, 4, 493–500. (p. 16)

NEWMAN, D., PEARN, J., BARNES, A., YOUNG, C., KEHOE, M., AND NEWMAN, J. 1984. Norms for hand grip strength. *Archives of disease in childhood 59*, 5, 453–459. (pp. 18, 46)

NGUYEN, B. AND CHAPARRO, B. 2010. ipad is best for reading, communicating, and gaming. *Usability News 12*, 2. (pp. 5, 21)

NICOLAY, C. AND WALKER, A. 2005. Grip strength and endurance: Influences of anthropometric variation, hand dominance, and gender. *International Journal of Industrial Ergonomics 35*, 7, 605–618. (p. 19)

NUDO, R., JENKINS, W., MERZENICH, M., PREJEAN, T., AND GRENDA, R. 1992. Neurophysiological correlates of hand preference in primary motor cortex of adult squirrel monkeys. *The Journal of neuroscience 12*, 8, 2918–2947. (p. 54)

OGREN, L. AND WONG, J. 2010. An analysis of game controller and touchscreen devices for input into a complex high-information display. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Volume 54 (2010), pp. 615–619. SAGE Publications. (p. 8)

PATRICK, E., COSGROVE, D., SLAVKOVIC, A., RODE, J., VERRATTI, T., AND CHISELKO, G. 2000. Using a large projection screen as an alternative to head-mounted displays for virtual environments. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (2000), pp. 478–485. ACM. (pp. 9, 37)

PEEBLES, L. AND NORRIS, B. 2003. Filling 'gaps' in strength data for design. *Applied Ergonomics 34*, 1, 73–88. (pp. 18, 19)

PERHINIK, M. 2010. Apple e-book reader device concept. (p. 15)

PETERS, M. AND DURDING, B. 1978. Handedness measured by finger tapping: A continuous variable. *Canadian Journal of Psychology/Revue canadienne de psychologie 32*, 4, 257–261. (p. 19)

PRATT, K. 2010. Netbook, ereader, or ipad?–that is the question. *Computers in New Zealand Schools 22*, 1/2. (p. 4)

R. GOSCINNY, A. B., J.J. SEMP. 2011. *Nicolas*. Phaidon Press. (pp. 23, 29)

RAJABIYAZDI, F. AND GEDEON, T. 2011. Interface for an ultra large tablet. (p. 45)

RAJABIYAZDI, F. AND GEDEON, T. 2012a. Comparing user performance on an ipad to a 17" backpad. In *International Workshop on Intelligent Interfaces for Human-Computer Interaction* (2012), pp. accepted. IEEE. (pp. 1, 45)

RAJABIYAZDI, F. AND GEDEON, T. 2012b. Hand grip strength on a large pda: Holding while reading is different from a functional task. In *International Workshop* *on Intelligent Interfaces for Human-Computer Interaction* (2012), pp. accepted. IEEE. (p. 1)

RASMUSSEN, T. AND MILNER, B. 1977. The role of early left-brain injury in determining lateralization of cerebral speech functions. *Annals of the New York Academy of Sciences 299*, 1, 355–369. (p. 48)

REEVES, B., LANG, A., KIM, E., AND TATAR, D. 1999. The effects of screen size and message content on attention and arousal. *Media Psychology 1*, 1, 49–67. (pp. 10, 57)

RUDCHENKO, D., PAEK, T., AND BADGER, E. 2011. Text text revolution: a game that improves text entry on mobile touchscreen keyboards. *Pervasive Computing*, 206–213. (p. 6)

SCHMIDT, S., OLIVEIRA, R., KRAHE, T., AND FILGUEIRAS, C. 2000. The effects of hand preference and gender on finger tapping performance asymmetry by the use of an infra-red light measurement device. *Neuropsychologia 38*, 5, 529–534. (p. 19)

SCOTT, J., IZADI, S., REZAI, L., RUSZKOWSKI, D., BI, X., AND BALAKRISHNAN, R. 2010. Reartype: text entry using keys on the back of a device. In *Proceedings of the 12th international conference on Human computer interaction with mobile devices and services* (2010), pp. 171–180. ACM. (pp. 5, 6, 7)

SEARS, A., REVIS, D., SWATSKI, J., CRITTENDEN, R., AND SHNEIDERMAN, B. 1993. Investigating touchscreen typing: the effect of keyboard size on typing speed. *Behaviour & Information Technology 12*, 1, 17–22. (pp. 5, 21)

SHEN, E., TSAI, S., CHU, H., HSU, Y., AND CHEN, C. 2009. Double-side multi-touch input for mobile devices. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems* (2009), pp. 4339–4344. ACM. (pp. 12, 14)

SPELCHAN, B. D. 2010. Four in a row. (p. 30)

TRIGGS, W., CALVANIO, R., MACDONELL, R., CROS, D., AND CHIAPPA, K. 1994. Physiological motor asymmetry in human handedness: evidence from transcranial magnetic stimulation. *Brain research 636*, 2, 270–276. (p. 53)

VAN STRIEN, J. AND BOUMA, A. 1988. Cerebral organization of verbal and motor functions in left-handed and right-handed adults: Effects of concurrent verbal tasks on unimanual tapping performance. *Journal of clinical and experimental neuropsychology 10*, 2, 139–156. (p. 19)

VOGEL, D., CUDMORE, M., CASIEZ, G., BALAKRISHNAN, R., AND KELIHER, L. 2009. Hand occlusion with tablet-sized direct pen input. In *Proceedings of the 27th international conference on Human factors in computing systems* (2009), pp. 557–566. ACM. (pp. 1, 13, 23)

WAYCOTT, J. AND KUKULSKA-HULME, A. 2003. Students' experiences with pdas for reading course materials. *Personal and ubiquitous computing 7*, 1, 30–43. (pp. 4, 5, 21)

WOBBROCK, J., MYERS, B., AND AUNG, H. 2008. The performance of hand postures in front-and back-of-device interaction for mobile computing. *International Journal of Human-Computer Studies 66*, 12, 857–875. (p. 23)

WOLF, K., MÜLLER-TOMFELDE, C., CHENG, K., AND WECHSUNG, I. 2012. Pinchpad: performance of touch-based gestures while grasping devices. In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction* (2012), pp. 103–110. ACM. (pp. 14, 59)

YEH, W. 2010. A marketing research of new digital readers and ipad in comprehensive aspect. In *Computer Application and System Modeling (ICCASM), 2010 International Conference on*, Volume 15 (2010), pp. V15–320. IEEE. (p. 3)