Beginner Performance with the GKOS Chorded Keyboard

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Master's Thesis
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July 2010

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Jussi Tarvainen: Beginner Performance with the GKOS Chorded Keyboard
Master's Thesis, 67 pages, 4 appendix pages
July 2010

The number of mobile computing devices is increasing at a very fast pace. A large number of today's mobile phones still have 12-key keypads for text entry. However, many of the novel smart phones are equipped with QWERTY keypads or virtual keyboards that provide better performance for text input.

This thesis reports a user experiment investigating the early learning phase of a six-key chorded keyboard method called GKOS. The experiment focused on the following questions: how easy is it to learn the basic key combinations of GKOS in order to type full sentences, how rapidly does GKOS typing speed increase in the early phase of learning, how does GKOS compare to the other common mobile text entry methods in terms of typing speed, and what kind of reception does the GKOS method get from mobile users with alternating experience of mobile text entry systems? QWERTY keyboards were modified as test devices, and two software applications were set up for the thesis' purposes. The user experiment consisted of a text entry pre-test phase, an eight-day GKOS learning phase, as well as a pre-experiment and a post-experiment questionnaire.

The major findings from the user experiment were positive. The users were able to quickly comprehend and learn the GKOS character map. The development of text entry skill was encouraging: there was a lot of diversity among the participants, but they had an overall improvement of 277% between the first and last phrase set. After a short learning phase, participants' mean GKOS text entry speed surpassed the mean multi-tap text entry speed. Based on the experiment results, we suggest GKOS to be further studied in the form of a longitudinal study and with test devices that better resemble the GKOS concept devices designed by the creator of GKOS.

The GKOS method is unlikely to become a successful competitor for QWERTY keypad and virtual keyboard in the mobile phone market in the coming years. However, the method might have potential in device categories and situations, where hunt-and-peck typing is not an option. For instance, in-vehicle infotainment systems (IVIS) could benefit from a GKOS implementation.

Keywords and terms: text entry, chorded keyboard, GKOS.

Contents

1. Introduction

For the last 15 years, mobile phones have gained increased importance both as business tools and as consumer devices. The number of mobile computing devices is increasing at a very fast pace. The International Telecommunication Union estimates that there will be 5 billion mobile subscriptions globally in 2010 [ITU-T, 2010]. On top of the mobile phones, also other mobile device categories such as netbooks and tablet PCs have emerged. As a result, people now use a variety of devices instead of just a desktop or laptop PC, and the devices are often equipped with various text entry methods that enable both the operation of the device and communication with other people [MacKenzie and Tanaka-Ishii, 2007].

A large number of today's mobile phones still have 12-key keypads for text entry. However, the development of 3G mobile networks and the fore-mentioned new mobile device categories have made the field of mobile text entry systems more diverse. For some years the high-end mobile devices have provided end-users a true Internet experience with features such as an e-mail client, a browser, GPS navigation, and video streaming capabilities. Consequently, these new use cases have introduced a demand for a robust text entry method. This is the main reason why many of the novel smart phones are now equipped with QWERTY keypads or virtual keyboards.

Text entry methods have been studied extensively in the field of HCI, and the growth of mobile market has naturally generated more interest for the research findings. Even though speed is a key feature for any text entry method, there are a lot of other aspects that can be and should be studied in the field of text entry. Such things are for instance accuracy during and after the input, and the learning rate and error rate of the method. We briefly introduce the common terms and methods related to text entry research in the subsections of this introductory chapter. In the very end of the introduction, we present some text entry rates measured for various text entry methods.

Current research of text entry spans from popular text entry techniques, such as QWERTY and multi-tap, to techniques requiring more advanced equipment such as eye trackers. In this thesis, however, we concentrate on common mobile text entry methods and a chorded keyboard method called GKOS. The common mobile text entry methods (multi-tap, predictive text, QWERTY keypad, and virtual keyboard) and their characteristics are briefly introduced in Chapter 2.

A chorded keyboard (a.k.a. chord keyboard or chording keyboard) is a computer input device that allows the user to enter characters or commands formed by pressing several keys together, like playing a chord on a piano. The earliest version of a chorded keyboard dates back to the first half of the 19th century. The history and research of chorded keyboards are discussed in Chapter 3. We will also focus on some of the findings by Widgor and Balakrishnan [2004] who conducted a study that compared single- and dual-handed multi-tap text entry performance with a chorded method called ChordTap. In addition, we point out results from a longitudinal study of novice users' learning rates on the Twiddler conducted by Lyons et al [2004].

In Chapter 4 we introduce the GKOS keyboard (Global Keyboard Optimized for Small Wireless Devices). GKOS is an open standard of a 6-key chorded keyboard. GKOS provides all the functions and characters found on a standard PC QWERTY keyboard (including cursor control, cut and paste, Alt, Ctrl, Insert, Tab, page up, etc.). GKOS is originally intended for tiny wireless terminals that could benefit from a text entry method that minimizes the space requirements for text entry keys.

Since the GKOS method has not been studied before, we decided to conduct a user experiment focusing on the early learning phase of the GKOS method. The experiment preparations, apparatus and schedule are discussed in Chapter 5. In order to conduct the experiment, QWERTY keyboards were modified as test devices, and two software applications were set up for the thesis' purposes. The user experiment consisted of a text entry pre-test phase, an eight-day GKOS learning phase, as well as a pre-experiment and a post-experiment questionnaire.

In Chapter 6, we report the results from our GKOS experiment. The major findings from the user experiment were positive. We continue the discussion about the experiment results in Chapter 7, where we compare our results with the findings of other chorded keyboard experiments and propose suggestions for future research of the GKOS method. In addition, the challenges and possibilities of the GKOS method are discussed. Chapter 8 summarizes the main points of the thesis.

1.1. Text entry evaluations

Text entry rates have to be evaluated differently whether the text is composed or copied. Since composing might require substantial thinking time and other considerations from the user, it makes the evaluation of actual text entry speed and results comparison difficult [Wobbrock, 2007]. Thus, researchers usually prefer the copying text method when evaluating text entry methods in controlled conditions [MacKenzie and Soukoreff, 2002]. Even when copying text, the research methods can differ. In some studies the researchers have required a synchronicity with the source text. This means that they disallowed the participants from entering incorrect characters [Venolia and Neiberg, 1994; Isokoski and Käki, 2002; Evreinova et al., 2004]. On the other hand, other researchers have conducted studies in which they decided to disable error correction mechanisms [Matias et al., 1993; MacKenzie and Zhang, 1999].

Unconstrained text entry evaluation paradigm is the most common and widely used experimental methodology [Soukoreff and MacKenzie, 2001, 2003; Wobbrock and Myers, 2006]. It is a more natural approach compared to the fore-mentioned text copying methods, as it allows the participants to type any printable characters and backspace is used for error correction. In addition, there are no distracting error beeps or other intrusions affecting the text entry. The participants are given simple instructions to enter text quickly and accurately. Participants' performance is saved on log files that show a detailed sequence of actions, such as keystrokes including corrections. After the experiment, the input streams are parsed and interpreted according to various measures [Wobbrock, 2007]. We will give a brief introduction to the key measures and variables related to text entry experiments in the following subsections.

1.1.1. Words per minute (WPM)

Words per minute (WPM) is a common measure of typing speed. On some occasions (e.g. on some typing tests found on the web), there is no distinguishing for short and long words. For instance, the words "mouse" and "indistinguishable" are both counted as one word. This method of course gives significantly different WPM results depending on how short or long the words are in the test phrases.

The fore-mentioned problem has led to a solution where individual words are not counted, but it is the keystrokes that matter. In WPM measurement a word is standardized to five characters or keystrokes. For example, "eight" counts as one word, but "eighteenth" counts as two. A space between words is also count as a character (e.g. "mouse trap" counts as two words). A standardized length for words in evaluating input speed enables a better comparison despite language and hardware differences. Such a standard has been around since about 1905 [Yamada, 1980]. A less common form for describing text entry speed is characters per minute (CPM).

It is important to note that WPM does not include the number of keystrokes made during the entry, but only the length of the transcribed string and the time it takes to produce it. The formula for computing WPM is presented below [Wobbrock, 2007]:

$$WPM = \frac{|T|-1}{S} \times 60 \times \frac{1}{5}.$$

In the WPM formula, "$|T|$" is the length of the final transcribed string entered by the subject. "S" is seconds that are measured from the first character to the entry of the last. The "60" is seconds per minute and the "1/5" is words per character. "-1" plays an important role in the equation. It is important to subtract one character from the length of the transcribed string, since it is common that the text evaluation software starts the timing when the first letter is entered.

Adjusted words per minute (AdjWPM) is an expansion of the WPM formula that takes into account the number of errors remaining in the transcribed string [Matias et al., 1993; Wobbrock et al., 2006].

1.1.2. Key strokes per character (KSPC)

The metric key strokes per character (KSPC) is often used to describe the efficiency of key-based text entry methods [MacKenzie, 2002]. KSPC is the average number of key strokes that are required to write a character. KSPC can both be used as a characteristic of text entry methods (how many key presses are required to generate a single character in a text entry method) or as a dependent variable in text entry evaluations (for measuring the number of errors and the amount of error correction activity). It is worth to note that the KSPC value is often dependent of the language being used and that KSPC is only one of the characteristics that influence typing speed. Thus, a low KSPC is not a guarantee for fast text entry. For instance, three presses on the same key can be faster than two presses on different keys.

1.1.3. Learning curves

Entry rates are often used by graphing WPM over time and model the points according to the power law of learning [Card et al., 1983]. Such models take the following form:

$$WPM = aX^{b}.$$

"*X*" is the variable "time" (for instance a session number), and "*a*" and "*b*" are fitted regression coefficients. The value for "*a*" is "initial performance" and the value for "*b*" determines the steepness of the curve. The result of fitting such curves allows the performance estimation in future sessions, especially if the goodness of fit (R^2) has a high value. [Wobbrock, 2007]

1.1.4. About error rates and efficiency methods

In order to determine typing speed accurately, it is important to take into account typing errors. If errors are not counted, good results could be generated just by pressing random keys. There are many different ways to calculate errors in text entry experiments. Especially, unconstrained text entry experiments that allow participants to type in a more natural way, make the tracking and analysing of errors even trickier. Most error metrics are concerned with the distinction between errors during entry ("corrected errors") and errors after entry ("uncorrected errors").

Even though error rates are an important research area in the field of text entry, we will only briefly introduce the main terms, since our GKOS experiment's main goals are to focus on the comprehension of the GKOS character map, learning rate of basic key combinations, acceptance of the method, and the learning curve in the early phase of learning.

KSPC can be used for quantifying errors by measuring the number of entered characters to the final number of characters in the transcribed string [Soukoreff and MacKenzie, 2001]. One of the limitations of this measure is that it makes no distinction between the correct and incorrect characters that the user has deleted during text entry.

Minimum string distance (MSD) is used to measure the accuracy of the resultant copied string. MSD gives a distance between two strings in terms of lowest number of error-correction operations that are required to turn one string to another [Soukoreff and

MacKenzie, 2001]. Available operations are “inserting a character”, “deleting a character”, and “substituting a character”.

There are many measures for describing the efficiency of a text entry method. For instance, KSPC and others like correction efficiency, participant conscientiousness, as well as utilized and wasted bandwidth. Character classes “correct” (C), “incorrect not fixed” (INF), “incorrect fixed” (IF), and “fixes” (F) are essential components in describing the equations. [Soukoreff and MacKenzie, 2003]

1.2. Text entry rates for different methods

According to the Guinness Book of World Records, current world record holder for fastest English language typing was Barbara Blackburn. She used the Dvorak Simplified Keyboard, and maintained 150 WPM for 50 minutes, and 170 WPM for shorter periods. She has been clocked at a peak speed of 212 WPM [McWhirter, 1985].

For comparison, rough estimates of WPM rates for different text entry methods are presented in Table 1.

Method	WPM	References
Normal speech / Stenograph	200	[GKOS-2, 2010]
Dvorak keyboard (world record)	170	[McWhirter, 1985]
QWERTY (good / advanced / expert)	40 / 60 / 120	[Brown, 1988; GKOS-2, 2010; Lyons et al., 2004]
Twiddler (expert)	60-65	[Lyons et al., 2004]
GKOS (expert)	40	[GKOS-2, 2010]
Matias Half-QWERTY	35-40	[Matias et al., 1993]
QWERTY keypad (on smart phones)	30-40	[AAS, 2010]
Virtual keyboard (beginner / advanced)	20 / 30	[AAS, 2010; Lopez et al., 2009]
Handwriting on paper	20-30	[Brown, 1988]
Twiddler (beginner)	25	[Lyons et al., 2004]
Stylus on screen (QWERTY layout)	25	[MacKenzie and Zhang, 2001]
PDA handwriting recognition	15-25	[Kristensson and Denby, 2009; Luo and John, 2005]
T9 (beginner / expert)	10 / 20	[James and Reischel, 2001; Silfverberg, 2007]
Multi-tap (beginner / expert)	8 / 15	[James and Reischel, 2001; MacKenzie et al., 2001; Widgor and Balakrishnan, 2003]

Table 1: WPM rate estimations for various text entry methods.

Text entry rates presented in Table 1 should not be considered as a common average for a certain text entry method, as they have not been gathered from an extensive number of text entry measurements. It is also worth noting that the physical features of devices alter, and thus generate significant differences in WPM even for the same text entry method. There are, for instance, hundreds of different feature phones (basic mobile phones) capable of producing text with the multi-tap method. If the text entry capabilities of these devices were to be compared, the results would differ. That being said, the list gives a rough idea about the performance of different text entry methods. According to this list it seems, unsurprisingly, that QWERTY keypad is the fastest text entry method available for today’s smart phones (30-40 WPM).

2. Common mobile text entry methods

This chapter briefly introduces commonly used text entry techniques for mobile phones. Currently, multi-tap and "predictive text" are the most common text entry techniques for standard mobile phones. On novel smart phones, however, QWERTY keypads and virtual keyboards are becoming more and more popular. There are also many other less popular text entry methods such as RollPad, SureType, and Swype. However, those methods along with methods based on speech recognition and eye tracking are not discussed in this thesis.

2.1. Multi-tap

A majority of existing mobile phones have a 12-key numeric keypad for text entry. The latest recommendation for the key arrangement from the ITU Telecommunication Standardization Sector (ITU-T) is visualized in Figure 1 [ITU-T, 2001].

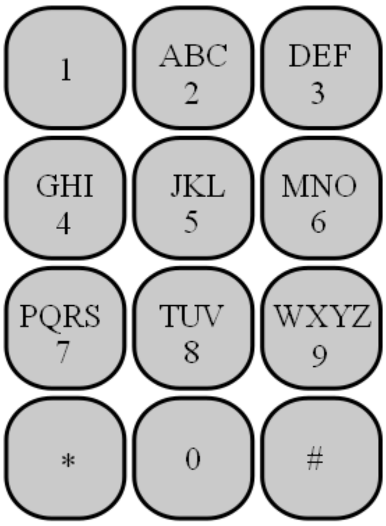

Figure 1: An assignment of the 26 letters a-z to the number keys of a numeric keypad.

Multi-tap is a text entry system designed for mobile phones. The alphabet is printed on the keys (starting from key "2"). The letters are placed on the number keys in three-letter or four-letter sequences (Figure 1). Multi-tap text entry is used by repeatedly pressing the same key to cycle through the letters for that key. For example, pressing the "5" key twice would indicate the letter "K". Pausing for a set period of time will automatically choose the current letter in the cycle, as will pressing a different key. The method is simple, but typing words that include consecutive letters from the same key (for instance in the word HIGH) is slow. In order to improve overall text-entry speed, some phone manufacturers use a special "time-out kill" key that allows a direct entry of the next character on the same key. Multi-tap has a higher average number of keystrokes per character (KSPC) (approximately 2.03) than many other text entry methods [MacKenzie, 2002]. In addition, according to various experiments, multi-tap's text entry speed is inferior to many other text entry techniques [James and Reischel, 2001; MacKenzie et al., 2001; Widgor and Balakrishnan, 2003]. Nevertheless, multi-tap is commonly used in text-messaging, as most standard mobile phones are equipped with 12-key keypads.

2.2. Dictionary-based disambiguation (T9)

Dictionary-based disambiguation is an improvement from the multi-tap technique. In dictionary-based disambiguation each key is pressed only once, and disambiguation is performed with the addition of linguistic information. The user simply presses the key corresponding to a desired letter and the key sequences are matched to those in the device's dictionary. For instance, pressing "4663" would translate to the word "home" on devices with an English language dictionary installed.

One of the most widely used dictionary-based disambiguation systems is T9, which has been licensed by most of the leading mobile phone manufacturers. Nowadays, billions of mobile phones around the world are equipped with T9 [Nuance, 2010]. Silfverberg et al. [2000] have predicted expert entry rates of 41 to 46 WPM for T9. However, in these predictions the researchers assume that all words entered are unambiguous and found in the dictionary. According to an analysis made by MacKenzie [2002] for English text entry, T9 has a KSPC close to 1. It is worth to note that his analysis indicated that the "next" key (used for cycling through the possible word options) is rarely used.

Common dictionary-based disambiguation text entry methods, such as T9, only use word frequency to determine what word the user is likely trying to type. Such systems would presume that by typing "4663" the user wants to write the word "home" and not "hood". This sometimes leads to a situation, where the user has to press the "next" key that is used to cycle through the word alternatives. This consequently leads to an increased KSPC. Gong et al. have addressed this issue and introduced a method that combines word frequency with semantic information [Gong et al., 2008].

It is obvious that T9 has its disadvantages. There are always words that are not in the in-built dictionary. In addition, numerals, abbreviations, and slang cannot be entered using T9. In such cases, a fall back system such as multi-tap must be used to input the desired word, abbreviation, or number. Another disadvantage is that users have to visually monitor the display to resolve ambiguities in text entry.

2.3. QWERTY keypad

For decades, QWERTY keyboards have been a dominant design for typewriters and personal computer keyboards. The first commercially successful typewriter produced by E. Remington and Sons in 1874 had a QWERTY-like character layout [Yamada, 1980]. In spite of this, of all the mobile phones in the world, only a few models are equipped with a QWERTY style keypad (Figure 2). That been said, it is worth to note that many new smart phones are equipped with QWERTY keypads.

QWERTY keypads, also referred as mini-QWERTY keyboards, have the same alphabet layout as traditional QWERTY keyboards, but function keys and number keypads are often left out. Text entry speed on QWERTY keypad does not reach the same level as on a QWERTY keyboard, since touch typing is not possible. Nevertheless, with QWERTY keypad powered devices it is possible to reach significantly higher typing speeds compared to multi-tap and T9 [Clarkson et al., 2005].

Along with Communicator devices, one of the first QWERTY keypad phones from Nokia was Nokia E70. This device from 2005 is also used in our GKOS experiment as a baseline device for QWERTY keypad measurements (Figure 2). An example of a novel QWERTY keypad phone is HTC's Touch Pro from 2008 (Figure 3).

Figure 2: Nokia E70 phone with a QWERTY keypad.

Figure 3: HTC Touch Pro.

2.4. Virtual keyboard

Touch screen enabled mobile phones, such as Apple's iPhone (Figure 4), do not have a keypad at all. Instead, text entry is possible with a virtual QWERTY style keyboard that pops up on the screen whenever text needs to be entered. Virtual keyboards have become more common as many phone manufacturers have followed Apple and released touch screen devices. One of the challenges for virtual keyboards is a higher text entry error rate when compared to QWERTY keypads. At least, according to Chicago-based usability consultancy User Centric, Inc, this is the case with iPhone's virtual keyboard [User Centric, 2007].

A lack of tangible keys is a likely reason why typing on a virtual keyboard can cause more errors. As the user cannot get touch feedback from touch screen's smooth glass surface prior to the key press, it is difficult to make sure the finger is over the right key. For this reason, Apple along with some other mobile device manufacturers provides a visual hint (enlargement) of a letter that is about to be typed when a finger is left on the touch screen surface. Obviously, typing speed reduces significantly if every letter is "double-checked" with this method. Martin et al. [2009] studied the effect of zoom function further in an experiment where novice typists were typing with and without the zoom function. There were no clear differences in text entry rate and error rate between the methods, but according to a post-experiment questionnaire the users seemed to appreciate the zoom function.

Figure 4: Virtual QWERTY keyboard on iPhone.

One great benefit of a virtual keyboard is that the keys are not fixed. Thus, the user could use a layout differing from QWERTY, for instance a DVORAK[1] keyboard, without the need to make any physical adjustments to the device. Research on optimizing virtual keyboards for stylus and one finger typing has produced layouts such as OPTI, FITALY, and ATOMIK [MacKenzie and Zhang, 1999; Zhai et al., 2002; Textware Solutions, 2009]. Despite the predicted high WPM figures, these optimized

[1] An optimized layout for English language to reduce inefficiency and fatigue

methods have not generated much interest. The main reason is probably the additional training that is required in order to reach a comfortable text entry speed.

Touch screen also provides a platform for new, imaginative text entry methods such as ShapeWriter. In shape writing, instead of tapping each letter explicitly, the user slides a stylus (or finger) over all of the letter keys in a word sequentially and the system then resolves what word the user intends to type and displays it on the screen [Zhai, 2006].

3. Chorded keyboards

This chapter explains the basics of chorded keyboards. We will briefly discuss the definition, history, and design background of chorded keyboards. Then we go through the pros and cons of chorded keyboards. We will also highlight some results of experiments performed for chorded keyboards in Section 3.1. In Section 3.2 we will introduce one more chorded keyboard: a 12-key typing device called Twiddler. Twiddler has produced some impressive results in experiments and we will focus on some of the findings from a longitudinal study of novice users' learning rates on the Twiddler conducted by Lyons et al. [2004].

A chorded keyboard (a.k.a. chord keyboard or chording keyboard) is a computer input device that allows the user to enter characters or commands formed by pressing several keys together, like playing a chord on a piano. The earliest known chord keyboard was part of the "five-needle" telegraph operator station, designed by Wheatstone and Cooke in 1836 [Wiki-C, 2010]. A chorded keyboard minus the board, typically designed to be used while held in the hand, is sometimes called a keyer. Modern chorded keyboard designs include models both for one-handed and two-handed use.

One example of an old commercial chorded keyboard is the Microwriter (Figure 5) that was designed in 1980 by Enfield Cie in the USA and sold in the early 1980s by Microwriter Ltd in UK [Old-Computers, 2010]. Microwriter is a hand-held portable word-processor with a chording keyboard. It enables a typing of all alphabet letters, numerals, and punctuations marks with just 6 keys. Microwriter did not become commercially successful, presumably due to the fact that is common for all the chorded keyboards: learning to type is difficult in the very beginning. On the other hand, some of the users who bothered to learn the system were impressed with its performance. A former Microwriter user states on the old-computers.com website that "*it was mindbending to learn, but after 7 days we were each very competent and thought it a marvellous machine*".

Figure 5: Microwriter by Microwriter Ltd.

Many chorded keyboard designs are based on the Braille system: a method that is widely used by blind people to read and write. It was developed by Louis Braille in 1825. The Braille system is based on a communication method called “night writing”[2]. Each Braille character is made up of six dots that are arranged in a rectangle containing two columns of three dots each (Figure 6). Especially GKOS key arrangements are similar to the Braille alphabet, since 6 keys (two columns of three keys) are used.

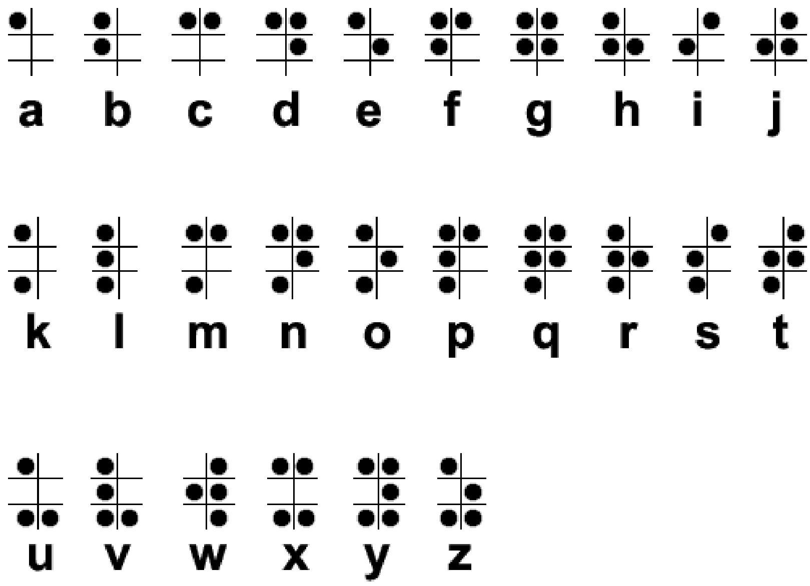

Figure 6: Braille alphabet.

Chorded keyboards have many advantages compared to other text entry methods, including QWERTY. Firstly, some chorded keyboards enable efficient one-handed typing leaving the other hand free. Secondly, chorded keyboards can also be built into a

[2] Napoleon's demand for a code that soldiers could use to communicate silently and without light at night

device that is too small to contain a normal sized keyboard. Finally, these keyboards can also be used with limited visual feedback: there is no need to look at the keyboard to determine where the fingers should be placed, as the fingers are not moved from one key to another. On the other hand, most chorded keyboards cannot be used by a hunt and peck method (looking for each key separately before striking it). Consequently, chorded keyboards require additional training before the text entry method is learned adequately and typing speed reaches a reasonable level. Thus, chorded keyboards are often considered suitable only for special tasks or occasions where traditional typing methods or devices cannot be used.

3.1. Research and experiments related to chorded keyboards

Chorded keyboards have been studied in the field of text entry. However, most of the implementations have not succeeded commercially. The first experiment reported on chorded keyboards dates back to 1965. Conrad and Longman [1965] described an alpha-numeric data input keyboard which "minimizes the reach movements which are an intrinsic feature of typewriting". In their chorded keyboard design two keys were pressed simultaneously to type a character. They carried out an experiment in which two groups of postmen were trained for seven weeks. One group learned to use a chorded keyboard and the other group worked on a standard typewriter. Learning rate for the chorded keyboard was better, as the "chording group" became operational two weeks sooner than the typists. After that, learning rate and error rate for both text entry methods were somewhat parallel. However, text entry speed for the chording group was better than for the typists.

In 1968, Douglas Engelbart and 17 other researchers demonstrated a revolutionary NLS (oN-Line System) that they had been working on over six years [Stanford, 2010]. NLS introduced a computer mouse among other innovations (for instance hypertext). One of the devices introduced in the demonstration was a 5-key chorded keyboard that has acted as an example for some other chorded keyboard designs.

In 1988, Gopher and Raij presented some of their results of experiments conducted on a two-handed chorded keyboard. Their keyboard comprises two panels of five keys, one each hand. The system enables fast skill acquisition, as subjects reached rates of 30-35 words per minute after 20 hours of training. With 60 hours of training, subjects reached entry rates close to 60 words per minute. The reported learning rate is significantly higher than for QWERTY. Gopher and Raij also pointed out that the new chording skill did not have a negative impact on participant's QWERTY keyboard typing performance. [Gopher and Raij, 1988]

Widgor and Balakrishnan [2004] conducted a study that compared single- and dual-handed multi-tap text entry performance with a chorded method called ChordTap. They used a Motorola i95cl phone. The multi-tap implementation used i95cl's built-in multi-tap engine, with a 2 second timeout and timeout kill. The participants were also allowed to use a “next” key to perform faster in multi-tap mode. Chording (Figure 7) was enabled by attaching momentary switches to the phone’s back and connected to the phone’s serial port. The desired character was chosen by pressing one to three of the three switches and one key on the numeric keypad simultaneously. For instance, letter “P” was typed by pressing the switch key on top (number “1” in Figure 7) and number key “7” on the keypad. Number keys “7” and “9” contain four letters. The fourth letter was typed by pressing any two switches or all three switches and a number key simultaneously. Everything in the experiment (including data presentation and collection software) was done on an i95cl device. [Widgor and Balakrishnan, 2004]

Figure 7: ChordTap prototype. The right image shows the chord keys mounted on the back of the phone. [Widgor and Balakrishnan, 2004].

The experiment had 15 participants (5 women, 10 men, 2 left-handed). The participants were randomly assigned to three groups of five persons. Every group used a different text entry method (one-handed multi-tap, two-handed multi-tap, and ChordTap). This approach was taken to prevent possible transfer effects between the different techniques. Before the actual experiment, the participants in the ChordTap group familiarized themselves with the method by typing one test phrase that required the use of all chord combinations for ChordTap.

Participants entered short phrases of text selected from MacKenzie and Soukoreff’s corpus [MacKenzie and Soukoreff, 2003]. Widgor and Balakrishnan chose to use these phrases, since they have been used also in some previous text entry studies involving multi-tap, thus allowing comparisons with previous work. The corpus’ high correlation of frequencies of letters to the English language is an asset. However, abbreviations commonly used in mobile text input are not taken into account in the corpus.

The experiment had a total of 16 blocks divided in two sessions. In each block the participants typed 20 phrases. Thus, a total of 4800 phrases were entered.

As Figure 8 shows, all three techniques began with roughly the same performance (average speeds of 7.62 WPM for one-handed multi-tap, 8.67 WPM for two-handed multi-tap, and 8.46 WPM for ChordTap). However, ChordTap users had an overall improvement of 90% between the first and last blocks, whereas one and two-handed multi-tap users improved their performance more moderately (45% and 39%). At the end of the experiment, average speeds were 11.05 WPM for one-handed multi-tap, 12.04 WPM for two-handed multi-tap, and 16.06 WPM for ChordTap.

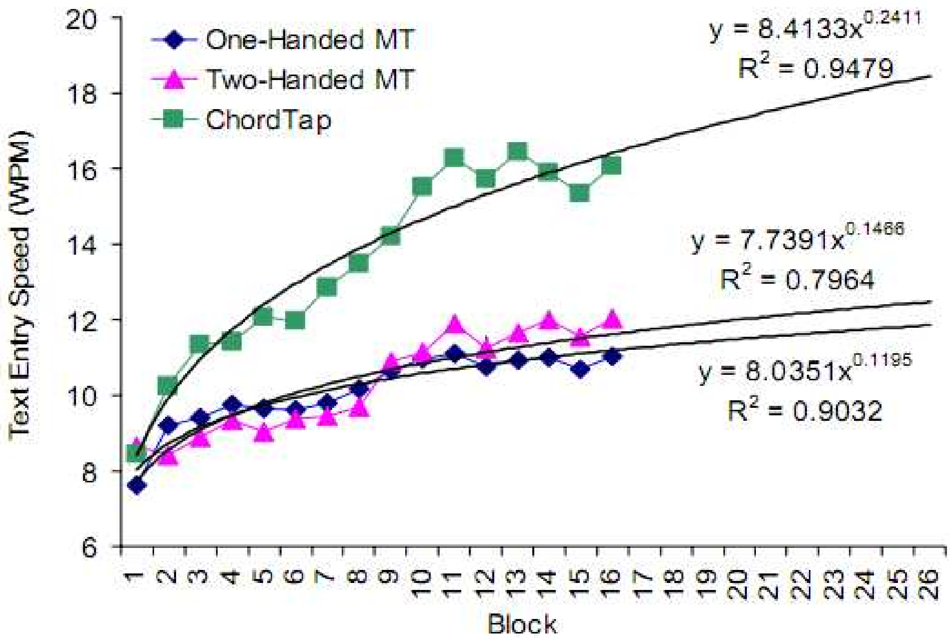

Figure 8: Entry speed (WPM) by technique and block for entire experiment. Best-fit power law of learning curve shows projected progress beyond the 16 blocks of measured data. [Widgor and Balakrishnan, 2004].

An interesting model of two-thumb chording on a phone keypad by Patel et al. [2009] has similarities with ChordTap. Patel et al. also present a chording method for a regular 12-key mobile keypad where all the chords are either one- or two-key chords. According to the researchers' Fitts's Law based performance model, an expert user of two-thumb chording could reach a text entry rate of 55.02 WPM.

3.2. Twiddler

Twiddler is a mobile one-handed chording keyboard with a 12-key keypad similar to the ones found in mobile phones. It has twelve keys arranged in a grid of three columns and four rows on the front of the device (Figure 9). Each row of keys is operated by one of the user's four fingers. Twiddler has several modifier buttons such as "Alt" on the top operated by the user's thumb. Users hold the device in the palm of their hand, keys facing away from their bodies. All five fingers can and should be used for typing.

Each letter of the alphabet can be typed on the Twiddler by pressing one or two keys concurrently. The Twiddler has also a multi–character chords (MCCs) feature. This means that the keyboard has chords for some frequent words and letter combinations such as ‘and’, ‘the’, and ‘ing’. Users can also define their own MCCs, which have a positive effect on the Twiddler’s number of keystrokes per character (KSPC) rate [MacKenzie, 2002]. HandyKey also developed an enhanced version of Twiddler (Twiddler2). HandyKey has been in financial trouble and it has affected both the development and availability of Twiddler devices. Recently, the development of Twiddler has been more active and a new version (Twiddler 2.1) should be available soon [HandyKey, 2010].

Figure 9: Twiddler by HandyKey [2010].

Research made on Twiddler has provided some impressive results. It has been stated that an experienced user of Twiddler averages speeds of 60 words per minute with letter-by-letter typing of standard test phrases [Lyons et al., 2004]. Such a high WPM rate would make Twiddler a very potential alternative to other text entry methods. In order to investigate this, Lyons et al. decided to conduct a longitudinal study of novice users’ learning rates on the Twiddler.

The experiment had 10 native English speakers as participants (2 females, 1 left-handed), who typed for 20 sessions using two different methods. Each session included 20 minutes of typing with both techniques (multi-tap and one-handed chording). The Twiddler device was used for both of the techniques. As in the ChordTap experiment, also Lyons et al. decided to use test phrases from MacKenzie and Soukoreff’s phrase set [MacKenzie and Soukoreff, 2003].

The researchers found that multi-tap typing is faster in the beginning (8.2 WPM versus 4.3 WPM). However, after four sessions, the difference is negligible. After the eighth session the participants typed faster with Twiddler. At the end of the experiment (session 20) multi-tap speed was 19.8 WPM and chording was 26.2 WPM. The researchers also noted that Twiddler typing performance would still increase after 20 sessions. The learning rate was more rapid for chording than for multi-tap.

The researchers also found that it could be possible to predict text entry performance for multi-tap and chording techniques based on QWERTY keyboard text entry rate. Table 1 shows each participant's QWERTY average WPM and the ratio of his or her chording and multi–tap rates during the last session to his or her QWERTY rate. There is clear consistency across participants despite the large range in QWERTY speeds. After twenty sessions, the average ratio for chording is 32.5% (s.d. 3.9), while the average ratio for multi–tap is 24.7% (s.d. 4.5). However, Lyons et al. admit that as the experiment had only 10 participants, more data needs to be collected to confirm that QWERTY performance really acts as a predictor for multi-tap and chording techniques.

QWERTY wpm	Chording (%)	Multi–tap (%)
113.9	32.3	23.0
111.1	28.0	21.0
94.8	31.9	23.3
86.8	30.0	22.4
83.5	33.8	25.8
82.3	29.3	23.8
74.5	29.9	17.6
61.5	36.6	29.9
58.5	31.4	27.2
54.1	41.3	33.3

Figure 10: Typing rates as a function of QWERTY speed. [Lyons et al., 2004].

4. GKOS

This section introduces a chorded keyboard method called GKOS. First, we explain the background of the GKOS method. Second, GKOS concept devices and software are briefly introduced. We also explain the basics of GKOS typing and finally, in section 4.4, we briefly list some typing speed estimations that have been made for GKOS.

4.1. Background information about GKOS

The GKOS keyboard (Global Keyboard Optimized for Small Wireless Devices) is a 6-key chorded keyboard. The first GKOS prototype was developed in 2000. The GKOS concept is an open source project initiated by Seppo Tiainen, who has been designing, testing, and specifying mobile telecommunications systems since 1976 [GKOS-1, 2010].

GKOS provides all the functions and characters found on a standard PC QWERTY keyboard (including cursor control, cut and paste, Alt, Ctrl, Insert, Tab, page up, etc.). It is intended for tiny wireless terminals that could benefit from a text entry method that minimizes the space requirements for text entry keys. Thus, GKOS also allows a bigger screen to be used on small mobile devices. GKOS could also be used in many other applications, for instance, on the back of tablet computers [GKOS-1, 2010].

4.2. GKOS concept devices and software

So far the GKOS concept has not had any commercial development [Wiki-C, 2010]. In addition, the GKOS text entry method has not been a subject of academic research. GKOS is mainly developed for two-handed text entry. However, one-handed typing is also possible if the device is small and the keys are placed in a suitable way as in the "GKOS Matchbox" concept device (Figure 11).

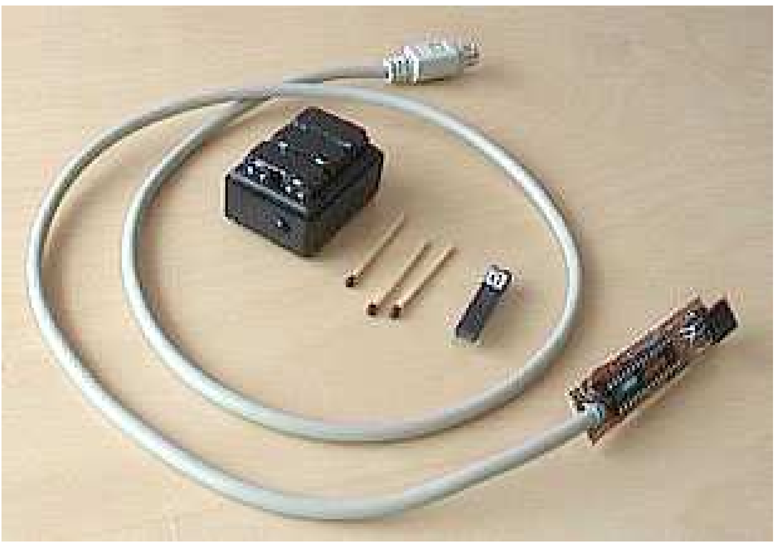

Figure 11: Small GKOS device prototype [GKOS-1, 2010].

Gkos.com provides information about the test devices, software, and use concepts that Tiainen has designed and built to demonstrate the GKOS method's capabilities. The website also includes instructions on how to build GKOS devices for various environments. GKOS typing can be tested with a QWERTY keyboard, by installing a Windows application or trying out a web browser implementation of GKOS. GKOS is also available for iPhone as a free application (Figure 12).

Figure 12: GKOS iPhone application [GKOS-1, 2010].

4.3. Typing with GKOS

Text entry on a GKOS system is fairly straightforward. To type letters (and numbers) at most two simultaneous key presses are required per hand. To be more precise, if one hand presses two keys, the other hand only needs to press at most one more key. Letters A, B, C, D, E, and F are typed by pressing one key (*Figure 13*). For instance, to type the letter "E" in GKOS the user presses the middle key with the right hand's middle finger. Letter "G" is produced by pressing the D and E keys simultaneously. To produce letter "J" three simultaneous key presses are required: D, E, and C.

Figure 13: GKOS concept device [GKOS-1, 2010].

Complete GKOS character set is presented in Figure 14. Each black 2-key combination is a shift function to obtain the rest of the letters in each group (or just produces the letter marked on it when pressed alone). Pressing all six keys simultaneously (ABC-123 function) will change between two character sets (the black and grey characters visualized in Figure 14). Capital letters can be produced by first pressing “SHIFT” (B and E key), and then pressing a key combination for a desired key. Two consecutive SHIFTs will set GKOS in CAPS LOCK mode.

The main principle in GKOS is that for frequently used characters (e.g. letters and common punctuation marks) only 1 to 3 simultaneous key presses are needed. Infrequently used characters require more simultaneous key presses or even a combination of simultaneous key presses. This makes the basic typing faster, and fewer errors are made as the other functions are not easily activated by mistake.

GKOS key combinations base largely on common alphabetical and numeral order. In addition, key combinations for some special characters resemble the shape of the first letter of those particular keys (e.g. “Ctrl” and “Delete” in Figure 14). Some key combinations resemble the shape of the key or symbol on a QWERTY keyboard (e.g. “Tab” and “Enter” in Figure 14).

Typing letters, numbers, and punctuation on a GKOS system is no more difficult than pressing Ctrl + Alt + Del on a PC keyboard [GKOS-1, 2010]. However, it requires some practice before a comfortable text entry speed is reached. This is a known challenge for every chorded keyboard method.

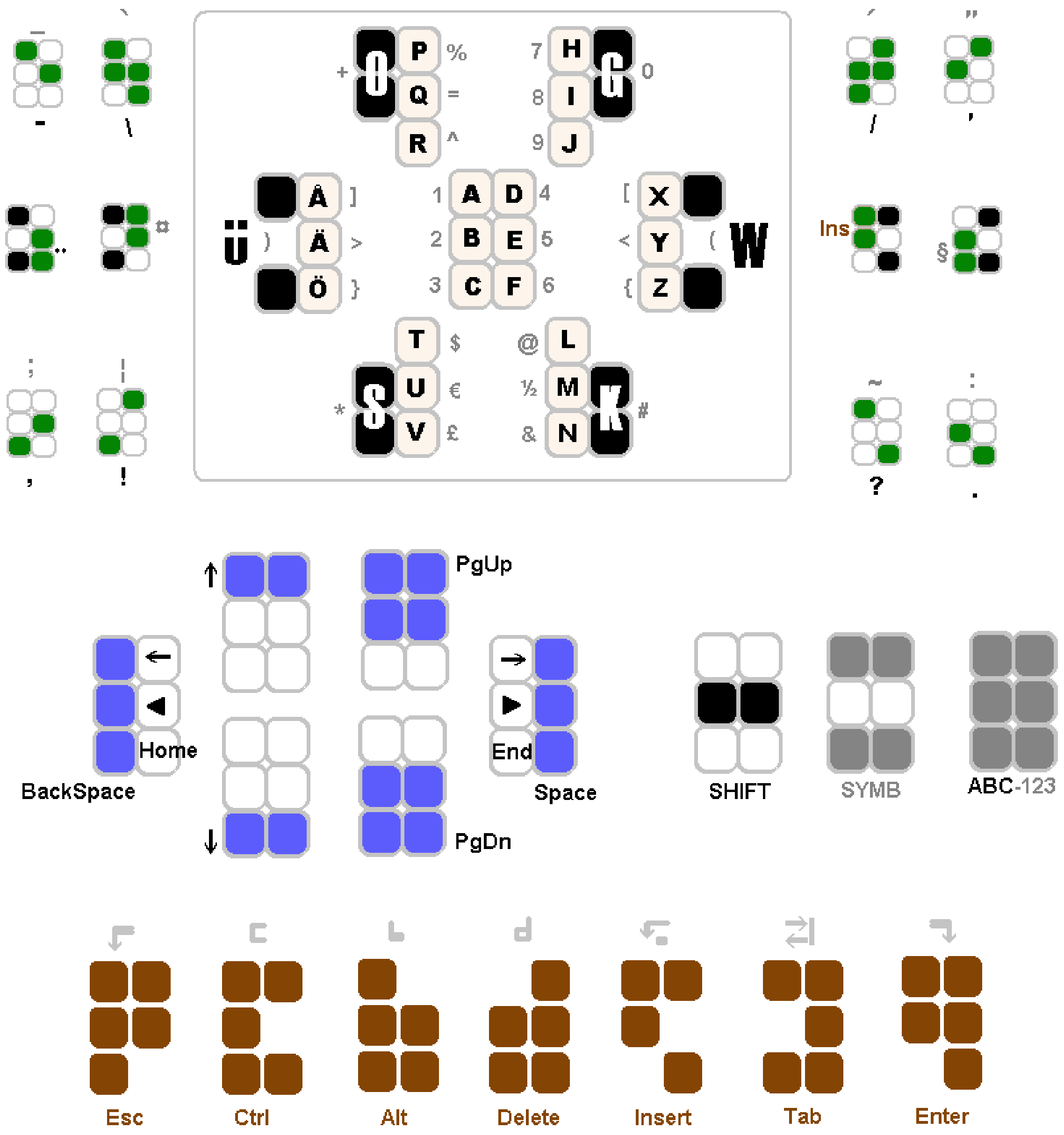

Figure 14: Complete GKOS character set [GKOS-1, 2010].

4.4. Typing speed estimations

According to GKOS's developer, it is possible to exceed a 10 word per minute typing speed with a small amount of practice. A speed of 20 WPM is also fairly easy to reach. When the user is familiar with the GKOS text entry method, typing speed reaches 40 WPM. An expert GKOS user can reach an impressive 60 WPM [Tiainen, 2008; GKOS, 2009]. It is worth to note that these estimates are purely based on Tiainen's own experiences. The texts he used in the small scale tests contained letters and punctuation [GKOS-1, 2010].

GKOS has also support for a chordon (chord-on-chord) technique and shortcuts that are likely to increase the overall typing performance as typing becomes partly parallel. In chordon typing (similar to Twiddler's multi–character chords) keys that belong to two or more consecutive chords are kept depressed also while the chord changes. According to Gkos.com a chordon shortcut is *"a two-character chordon which is preceded by, and ends in, an all-keys-released condition, and consists of characters of which at least one is a special character belonging to this group of characters"*. However, since both of these techniques are aimed at typists who are familiar with the GKOS system, we did not include them in our experiment.

5. Experiment

A user study that investigated the early learning phase of the GKOS text entry system is presented in this chapter. There are six sections in this chapter. The goals of the user study are discussed in the first section. The second section briefly explains the user experiment procedure. The user experiment participants are introduced in the third section, and the apparatus in the fourth section. A pilot test setup is explained in the fifth section, and the user experiment test phrases that found their final form after the pilot test are discussed in the sixth section.

5.1. Goals

The main goal of the user experiment was to investigate the feasibility of the GKOS text entry system when compared to current mobile text entry methods. There are four initially set research questions. First, how easy is it to learn the basic key combinations of GKOS in order to type full sentences? Second, how rapidly does the typing speed increase in the early phase of learning? Third, how does GKOS compare to the other common mobile text entry methods in terms of typing speed? Fourth, what kind of subjective evaluation does the GKOS system get from mobile users with alternating experience of mobile text entry methods?

The question about learning the GKOS key combinations is one of the key issues in this thesis. Since GKOS is a chorded keyboard method, hunt-and-peck typing is not possible, except when a character map is provided with the keyboard. If the user is constantly checking the finger positions from such a map, it significantly decreases his typing speed. Therefore, it is important that the basic key combinations of GKOS are easy to learn and comprehend. Tiainen [2008] mentioned that he put a lot of effort in designing the key combinations of GKOS and in visualizing the character map. This thesis aims to find out how well the key combinations and character map are understood by inexperienced users of GKOS.

The steepness of the GKOS learning curve in the early phase of learning is the second question that was investigated in our user experiment. Previous studies performed for chorded keyboards have reported quite impressive results [Gopher and Raij, 1988; Lyons et al., 2004] and we were expecting GKOS to reach a somewhat similar level. This thesis will also point out whether novice GKOS typists can really reach the typing speed estimated by Tiainen (discussed in Section 4.4).

Yet another interesting question that this thesis wants to highlight is GKOS typing method’s comparison to the other common mobile text entry methods. We wanted to see if the GKOS participants were able to surpass some of the common mobile text entry methods in regard of text entry speed during the GKOS learning phase.

The subjective evaluations of the GKOS method were expected to reflect the empirical data gathered from the participants' performance during the experiment. We were also keen to find out whether the participants had a good knowledge of how their GKOS typing performance compares to the other methods. The subjective evaluations were also expected to give some more knowledge of the possible weaknesses of the GKOS method, as well as give some information about the potential of the GKOS method in commercial products.

5.2. Procedure

The GKOS experiment consisted of three parts. The first part included a background questionnaire (Appendix 1), baseline measurements for common mobile text entry methods and an introduction to GKOS typing. The participants were instructed to type the test phrases as fast and as correctly as possible. The second part was a 4-day learning phase of GKOS that participants conducted independently. The participants were also encouraged to conduct an additional 4-day learning phase. The third and final part was a post-experiment questionnaire with some additional questions asked by the researcher if necessary (Appendix 2). (Figure 15)

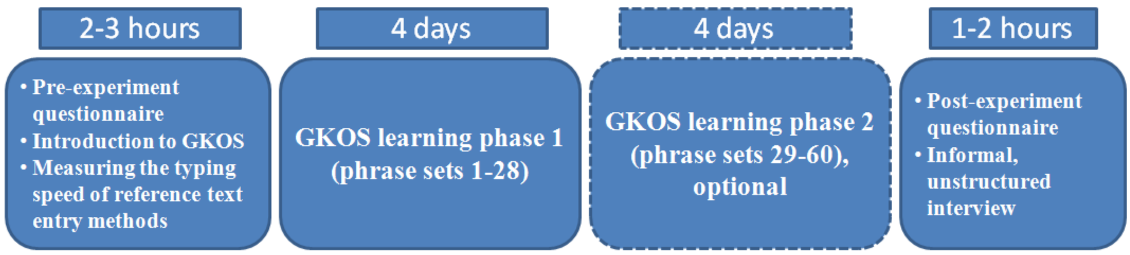

Figure 15: GKOS experiment schedule.

The baseline tests for common mobile text entry techniques included multi-tap, predictive text (T9), QWERTY keypad, and virtual keyboard. Also QWERTY keyboard typing speed was measured for reference. The devices that were used to determine the baseline results for these methods included Nokia E65 for multi-tap and T9, Nokia E70 for QWERTY keypad, and iPhone 3G for virtual keypad. The participants were allowed to familiarize themselves with the reference mobile text entry methods. It was made sure that the participants knew how to type the required characters with each device before the text entry performance was measured.

Since we were interested to find out how the GKOS method would compare to participants' preferred text entry method and currently used device, the participants were encouraged to type the baseline tests with their own devices when suitable. As a result, most participants ended up typing multi-tap and T9 measurements with their own devices. The QWERTY keyboard test was conducted with participants' own computer keyboards.

The main part of the user experiment, the GKOS learning phase, was based on a modified QWERTY keyboard that acts as a GKOS typing device, a monitor/driver software that enables GKOS typing on a PC running the Windows operating system, and a software that displays test phrases and monitors participant’s typing performance. This apparatus is further explained in Section 5.4 after the introduction of user experiment participants.

5.3. Participants

The GKOS evaluation had 10 participants, 7 male and 3 female. Most of the participants (8 out of 10) were in their late twenties or early thirties. Two of the participants were older (59 and 60 years). In addition to the user experiment participants, one participant, a 32-year old female, conducted a pilot test. All the participants were right-handed. The participants did not receive any other payment for their efforts but a gift worth of €7.5 or €15. The €7.5 gift was to be given for those who trained GKOS for 4 days and €15 for participants who did the complete 8-day training. In the end, all the participants trained GKOS for 8-days.

The participants had varying knowledge of mobile text entry methods. Participants’ experience levels of mobile text entry methods were clarified with the help of a pre-experiment questionnaire (Appendix 1). The response alternatives were “have used over a year”, “have used for couple of months up to a year”, “have tried at some point”, and “no experience”. The experience was considered good if the participants had been using the method for months.

Everyone was familiar with the multi-tap method; they had been using the method over a year. Other methods were less known. 5 out of 10 participants had a good experience of T9, 4 participants had tried it and only one did not have any experience of T9. 6 out of 10 had no experience of virtual keyboards and 5 of this group also lacked experience of QWERTY keypads. 3 out of 10 were experienced users of QWERTY keypads, and 2 out of 10 had some experience. Only one participant was an experienced user of a virtual keyboard and 3 had tried it. Half of the participants said that their preferred mobile text entry method is multi-tap. 4 preferred T9 and one preferred QWERTY keypad.

All the participants understood the given instructions and felt comfortable using both the provided software and the GKOS test device.

5.4. Apparatus

There were quite a few arrangements regarding the apparatus. A detailed description of the GKOS user experiment hardware and software is presented in this section. First, the process of finding and modifying a suitable device for GKOS test device is narrated. Second, the GKOS Monitor/Driver program is briefly introduced. The third and final part of this section explains the typing test application that was used for displaying GKOS phrase sets and monitoring the text entry performance.

5.4.1. GKOS test device

Since there is only a very limited number of GKOS prototype devices in the world (and most of them are different from each other), alternative ways in acquiring suitable test devices had to be investigated. GKOS website (gkos.com) contains information about testing GKOS on a QWERTY keyboard. On the website it is suggested that typing with QWERTY keyboard is done using keys “S”, “D”, “F”, and “J”, “K”, and “L”, as these keys do not cause conflicts on most of the contemporary QWERTY keyboards. A conflict-free design means that when all six keys are pressed down simultaneously, it will produce six different letters (in random order). Another good thing with the SDFJKL-layout is that it enables an ergonomic typing experience. One downside is that typing is significantly different from GKOS prototypes, where the keys are placed on the back of the device. Another downside is that the SDFJKL-layout is horizontal and thus significantly affects the readability of the GKOS character map (Figure 16) in which the key layout is vertical. Modifying the character map was out of the question, since the readability of the vertical character map was one of the things we wanted to investigate in our experiment. Because of the fore-mentioned problems, the SDFJKL-layout alternative was discarded.

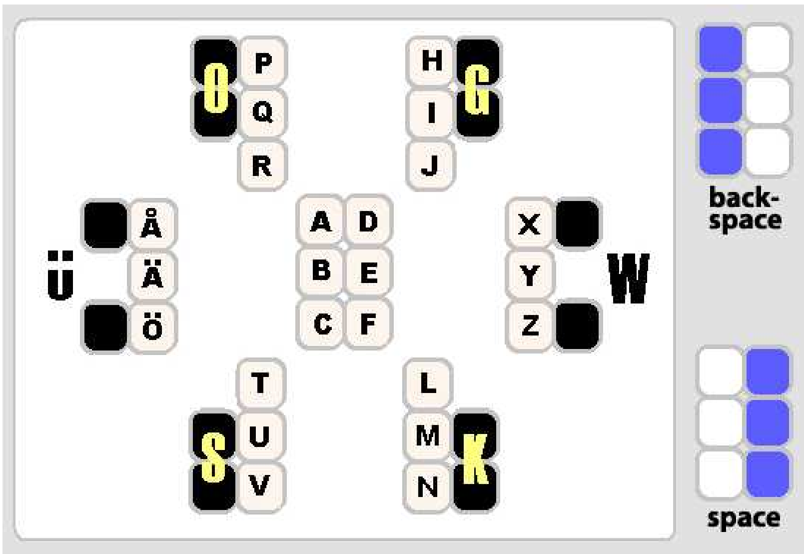

Figure 16: A simplified version of the GKOS character map.

A discussion with Mr. Tiainen (the creator of GKOS) raised an idea of using a USB number keypad as a GKOS device. A USB number keypad is small enough to be used with keys facing down, thus providing somewhat similar feel than the existing GKOS prototype devices. However, in order to make a number keypad conflict-free the keypad needs to be modified. Gkos.net website provides detailed instructions on how to do this. In spite of being a fairly good idea, also USB number keypads were discarded as a test device. One reason was that many of the current USB number keypads do not have a circuit board but a printed circuit board (PCB) that makes the modification somewhat more difficult. In addition, a thin USB number keypad did not feel very ergonomic as a GKOS device.

Finally, a decision regarding GKOS test device was made, when it was found out that some older QWERTY keyboards can produce letters “T”,”G”,”B”, and “O”,”K”,”M” without a conflict. Five equally conflict-free keyboards were found and modified for test purposes by removing all the keys, excluding keys “T”,”G”,”B”,”O”,”K”, and “M”. Finally, the simplified GKOS character map was attached on every keyboard over the remaining keys (Figure 17).

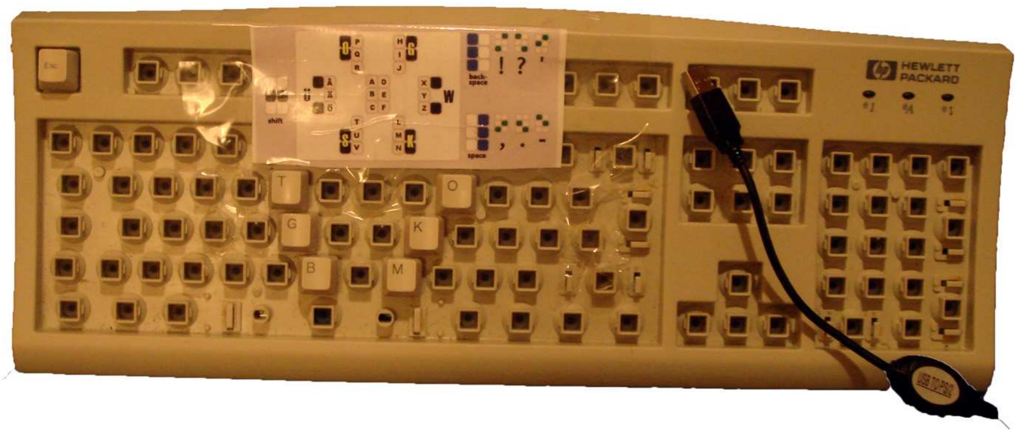

Figure 17: GKOS test device.

5.4.2. Software

Since the participants were typing the GKOS test phrases at home without the possibility to get instant help from us, the required software had to be very simple to install and use. The required programs and files were placed in one folder called “GKOS Test” and this folder was then copied to a USB memory stick. Since the programs required no installation, the participants only had to plug the USB stick in their computer’s USB slot, open the “GKOS Test” folder, and start the programs.

In order to be able to type with a GKOS-modified keyboard on a PC, it is required to start the GKOS Monitor/Driver program (gkos.exe) from the USB stick. The gkos.exe was especially modified for the GKOS experiment by Seppo Tiainen (version 0.71). The modified version of gkos.exe is a simplified version that prevents the users from typing unnecessary characters. With the modified version it is only possible to type “space”, “backspace”, and letters from A to Z as they were the required characters in the GKOS experiment in order to type the test phrases from MacKenzie and Soukoreff’s corpus [MacKenzie and Soukoreff, 2003]. In addition, letters Ü, Å, Ä, and Ö were enabled even though they were not necessary in the experiment. The test phrases used in our experiment are explained in more detail in Section 5.6.

In order to restore normal QWERTY typing, GKOS Monitor/Driver has to be shut down. It is worth to note that the typing instruction figure in gkos.exe program window refers to the default SDFJKL-keys, but this misinformation did not cause any problems in the experiment (Figure 18).

Figure 18: GKOS Monitor/Driver version 0.71.

Another program required to start before proceeding with the exercises is an application that contains the test phrases and also monitors and logs participant's text entry performance.

The main concern in choosing the monitoring software for our GKOS experiment was to find a program that would minimize the possibilities to perform unnecessary and possibly harmful actions. With this we mean actions that would affect the test results, make the results useless, or prevent participants from finishing the GKOS training phase successfully.

One of the considered text entry software was Poika Isokoski's TimTester [Isokoski, 2010]. It is a Java application that provides keyboard event logging as well as good analysis tools. However, TimTester was not chosen, because of the possible problems it could have caused during the experiment. For instance, some participants might not have had Java runtime installed on their computer and they might have had problems operating the TimTester program without external help.

Finally, we decided to use a free version of TypingMaster Typing Test software (version 6.30) [TypingMaster, 2010]. The good thing in Typing Test software is its simplicity. It does not require installation, the user interface is very simple, and test phrases can be pre-configured into it. However, the software is not exactly designed for text entry experiments, but intended for exercising keyboard typing skills. As a result, the software is not quite perfect for GKOS or any other text entry experiment purposes, as it lacks some preferred features such as keyboard event logging. This means that the aggregated data is not exact enough so that it would be possible to analyze various causes for typing errors in detail.

Typing Test software is started in a similar manner as gkos.exe: by double-clicking a program icon in the GKOS Test folder. This opens up Typing Test welcome screen (Figure 19). In the welcome screen, the user can choose a default name "GKOS Test User" from the list. The user can also create his or her user name by clicking the "I am a new user..." link. Such action opens up a dialogue window that contains a text box where the user can type his or her name. When the user has selected the default user name or typed his or her alias, he or she can then move on to the main screen by pressing a right arrow symbol in the bottom right corner of a screen.

Figure 19: TypingMaster Typing Test welcome screen.

In the main screen the user can choose a test phrase from the "Test Text" list by clicking it (Figure 20). Text phrase files were named clearly (e.g. day2-phrases-9.txt) guiding the participants to choose and type the phrases in the right order.

"Duration" drop-down box in the top right corner allows the user to choose how long is given to complete the phrase set. In the GKOS experiment, duration was set as "free", since the number of phrases that every participant typed was fixed, and the phrases were to be typed from start to finish. "Completed tests" list shows which phrases the user has already typed.

Moving on to the typing view can be done by clicking the "Next" arrow on the bottom right corner of the screen.

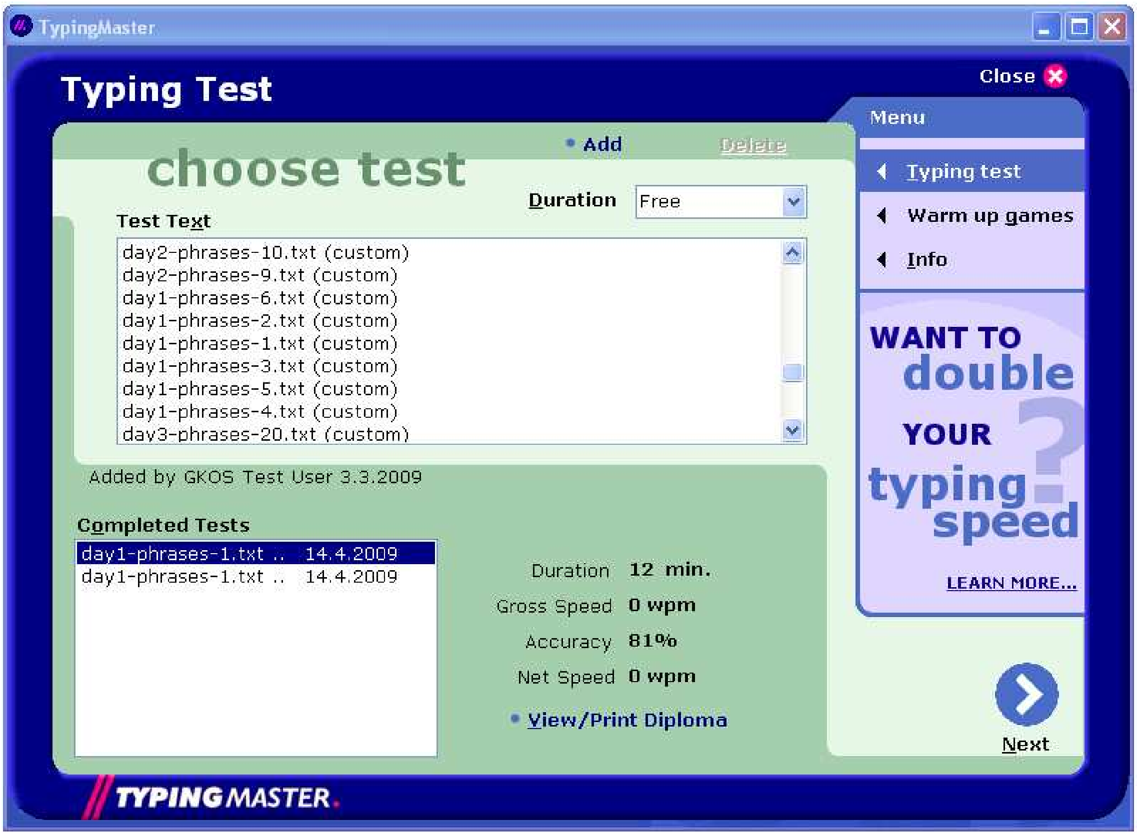

Figure 20: TypingMaster Typing test main screen.

The typing screen shows the phrases in the top left corner. Default color for the words is black, but the words that the user has already typed are shown in light green. The word that is currently being typed is underlined. The produced characters are shown in the lower part of screen, and new ones appear letter by letter during the typing process. If the user makes a mistake, the mistyped word is underlined in blue color. The percentage figure in the upper right corner shows how far the participant is in the current phrase set. (Figure 21)

It is important to know that Typing Test allows the user only to correct errors in the word that is being typed. A space key indicates for the program that a word is finalized and cannot be modified any more. This restricting feature was explained to the participants before the test.

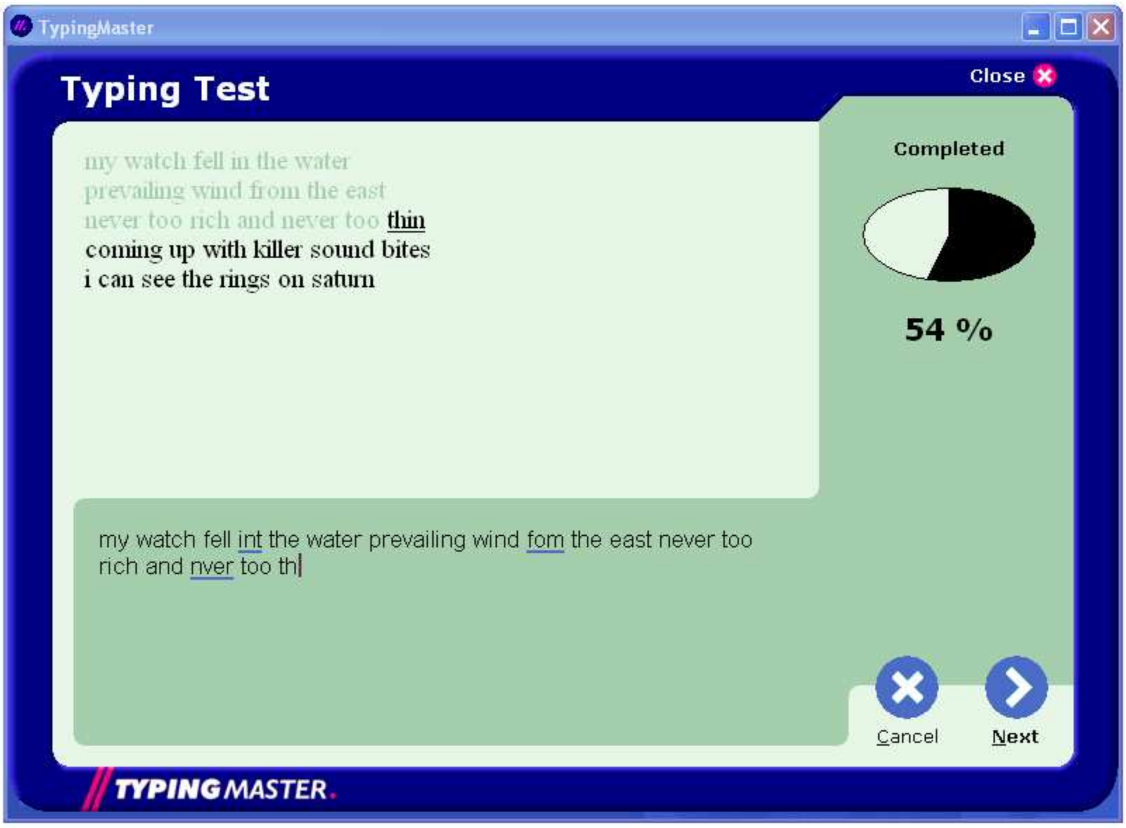

Figure 21: TypingMaster TypingTest typing screen.

After the last word is typed, a dialogue window pops up and informs that the test has been completed. The user gets to the results screen by pressing the “Next” button located in the lower right corner. In the results screen the user can see rounded figures of his performance (Figure 22). More detailed results can be seen by clicking a “Print Diploma” link in the bottom of the page. The “Next” button takes the user back to the main view, from where it is possible to choose the next phrase exercise from the “Test Text” list.

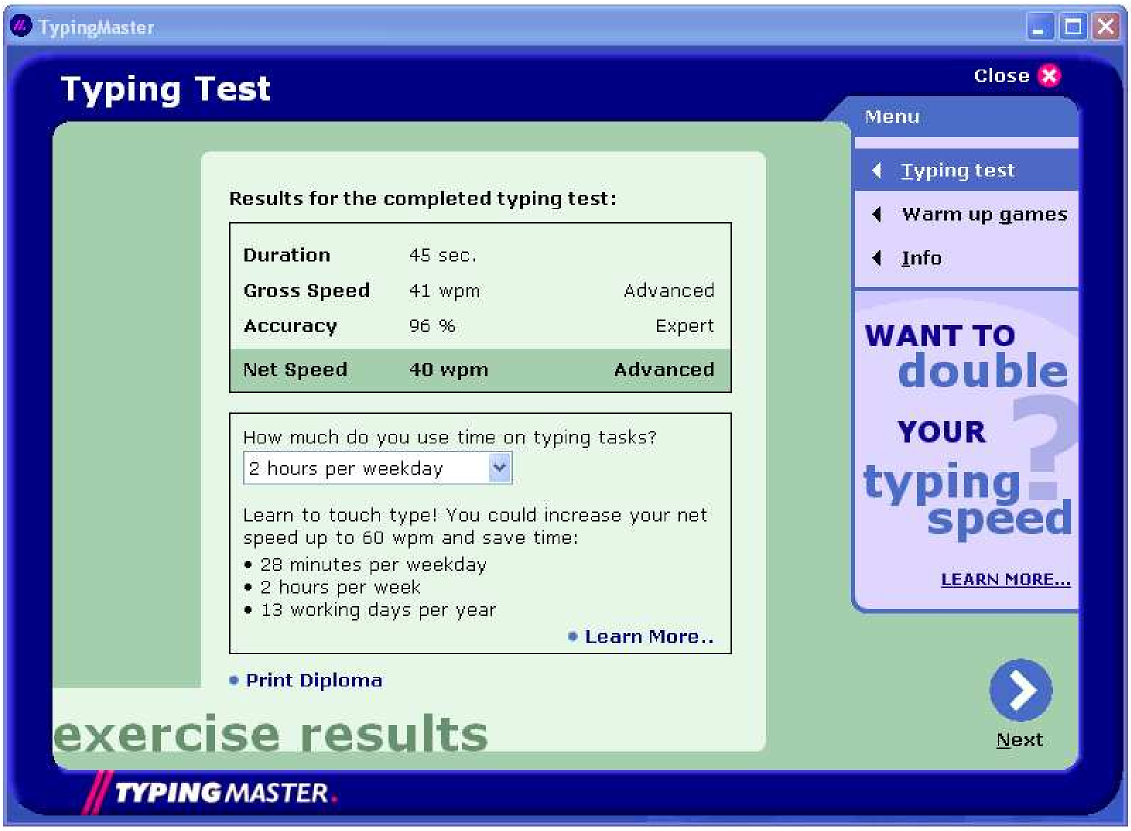

Figure 22: TypingMaster Typing Test results screen.

5.5. Pilot test

A pilot test was conducted with one participant (who was not participating in the actual experiment) in order to evaluate the understandability of the pre-experiment questionnaire and the suitability of GKOS typing experiment phrase sets. The pilot test participant was a 32 year old female. She had a reasonably good knowledge of mobile text entry techniques and a lot of hands-on experience of the Nokia E70 device that is equipped with a QWERTY keypad.

At first, the pilot test participant answered the background questionnaire in the presence of the researcher. The participant was allowed to ask questions if some of the questions were not understandable. Some of the text entry terms (e.g. multi-tap and T9) in the questionnaire caused some hesitation even though the terms were further explained in brackets and with pictures (Appendix 1). There was, however, no need to make changes to the pre-test questionnaire, since the researcher would also be present when the actual GKOS experiment participants were filling the pre-test questionnaire.

The main interest of the pilot test was to see if the apparatus and test phrases would be suitable for our GKOS experiment. At first, the participant conducted baseline text entry tests for QWERTY keyboard, multi-tap, T9, QWERTY keypad (E70 and E71), and virtual keyboard. The participant typed the QWERTY keypad test with two different devices, since a QWERTY keypad is her preferred text entry method in real life, but she had just recently started to use the E71 device and therefore the typing for that device was not yet familiar. A test for Nokia E70 was also conducted, since that device was her previous phone and also a default reference device for QWERTY keypad tests in the GKOS experiment.

All the tests were timed with a mobile phone stopwatch and the results were scribed down in one second accuracy. The stopwatches used in the experiment were iPhone 3G's native stopwatch application and a free stopwatch application for Nokia E65. E65 stopwatch was used when the virtual keyboard test was performed with the iPhone. The reference text entry phrase sets seemed to suit for the GKOS experiment and therefore no changes were made for those phrases.

The actual GKOS learning phase pilot test contained five blocks. The participant typed one block per day and each block contained six 5-sentence phrase sets. Thus, the total number of phrase sets in the beginning of the GKOS learning phase pilot was 30. The 5-day learning period went well, as the participant was able to conduct the test without any external help. However, there were a couple of occasions where the participant started to type the same phrase set again, since she did not remember to choose the next phrase set from the main view.

The pilot test participant's GKOS typing speed was also increasing significantly as the learning period progressed. After the 5-day period it was clear that the learning had not yet reached a stationary phase. Since the pilot participant was willing to continue the experiment, another 5-day phrase set was generated and set up in the TypingTest application. After 60 phrases the growth rate seemed to be diminishing, but in order to reach a stationary phase, a much longer GKOS learning period would have been necessary (Figure 23). In the end of the experiment, the pilot test participant's GKOS text entry rate was around 17.5 WPM, according to the power trendline (R^2=0.9005).

Since the ten GKOS participants were to receive only a modest compensation for their efforts as participants, 60 phrase sets seemed like a comfortable maximum amount of typing per participant. However, 60 phrase sets would anyhow be enough to give an idea of the performance in the early phases of learning the GKOS method.

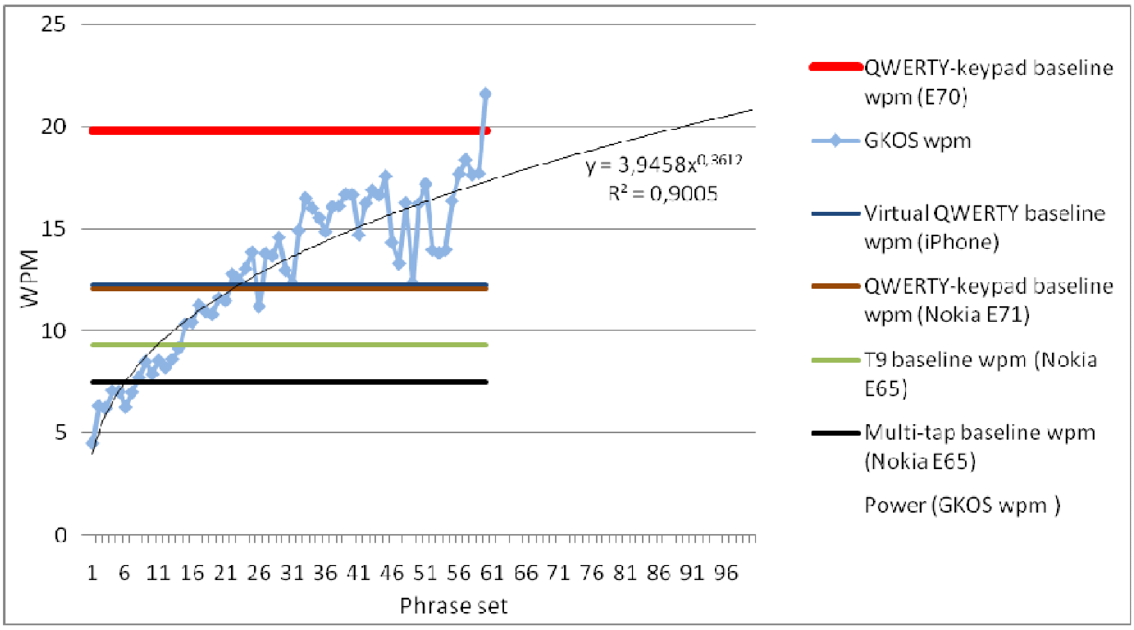

Figure 23: Pilot test participant's GKOS typing test results.

5.6. Test phrases

The GKOS experiment test phrases were taken from a 500 phrase list collected by Mackenzie and Soukoreff [MacKenzie and Soukoreff, 2003]. The phrase set contains no punctuation and only some uppercase characters (that were changed to lower case in the GKOS experiment).

Each GKOS experiment phrase set contained five sentences from MacKenzie and Soukoreff's list. The test phrases were taken from the phrase list in somewhat random order. This means that the number of characters per phrase set was monitored, when the phrase sets were made. Each phrase set contained on average 151 characters, the shortest set having 146 characters and the longest 155 characters. No attention was paid on equalizing the average word length in the phrase sets. As a result, some phrase sets are potentially slightly more difficult to type than others.

All sixty phrase sets as well as the pre-test phrases for the reference text entry methods (QWERTY keyboard, multi-tap, T9, QWERTY keypad, and virtual keyboard) contained unique sentences. Unique phrases guaranteed that participants' typing speed would not increase because they happened to memorize some of the phrases that they were typing. Since some of the participants' QWERTY keyboard typing speed was expected to be relatively high, the QWERTY keyboard typing phrase set contained ten sentences instead of five. Hence, the total number of sentences taken from MacKenzie and Soukoreff's test phrase corpus and used in the GKOS experiment was 330 (10 for QWERTY keyboard, 20 for mobile text entry methods, and 300 for GKOS method's learning phase). The following is an example of a phrase set used in the GKOS experiment:

these barracks are big enough
sing the gospel and the blues
he underwent triple bypass surgery
the ropes of a new organization
peering through a small hole

The reference text entry method phrases (QWERTY keyboard, multi-tap, T9, QWERTY keypad, and virtual keyboard) were printed on A4 sheets (font: Courier New, font size: 20). During the experiment, the sheet was in front of the participant, except for the QWERTY keyboard test where the sheet was placed next to a keyboard.

6. Results

The results of the GKOS experiment are presented in this chapter. We will first take a look at the baseline figures of the reference methods and the GKOS text entry speed development during the eight-day learning phase. In Section 6.2 we briefly go through the findings related to text entry errors and difficult characters. In the third section we present the results from the post-experiment questionnaire.

6.1. Text entry speed development

After a successful pilot test, we expected that the GKOS experiment participants would manage to learn the GKOS method reasonably well during the short learning period. These assumptions were backed up by encouraging results from models and experiments related to other chorded text entry methods [Widgor and Balakrishnan, 2004; Lyons et al., 2004; Patel et al., 2009]. On the other hand, since our group of 10 participants had such different backgrounds and varying experience of text entry methods, we also expected to see a lot of variance in the results.

The mean figures consisting of participants' results for reference entry methods and GKOS are shown in Figure 24. As expected, the individual results for each method varied a lot. For instance multi-tap results ranged from 4.67 WPM to 18.26 WPM, mean being 11.73 WPM. Mean speed for GKOS was 3.4 in the beginning and, according to a power trendline, 12.8 WPM in the end. Thus, GKOS participants had an overall improvement of 277 percent between the first and last phrase set.

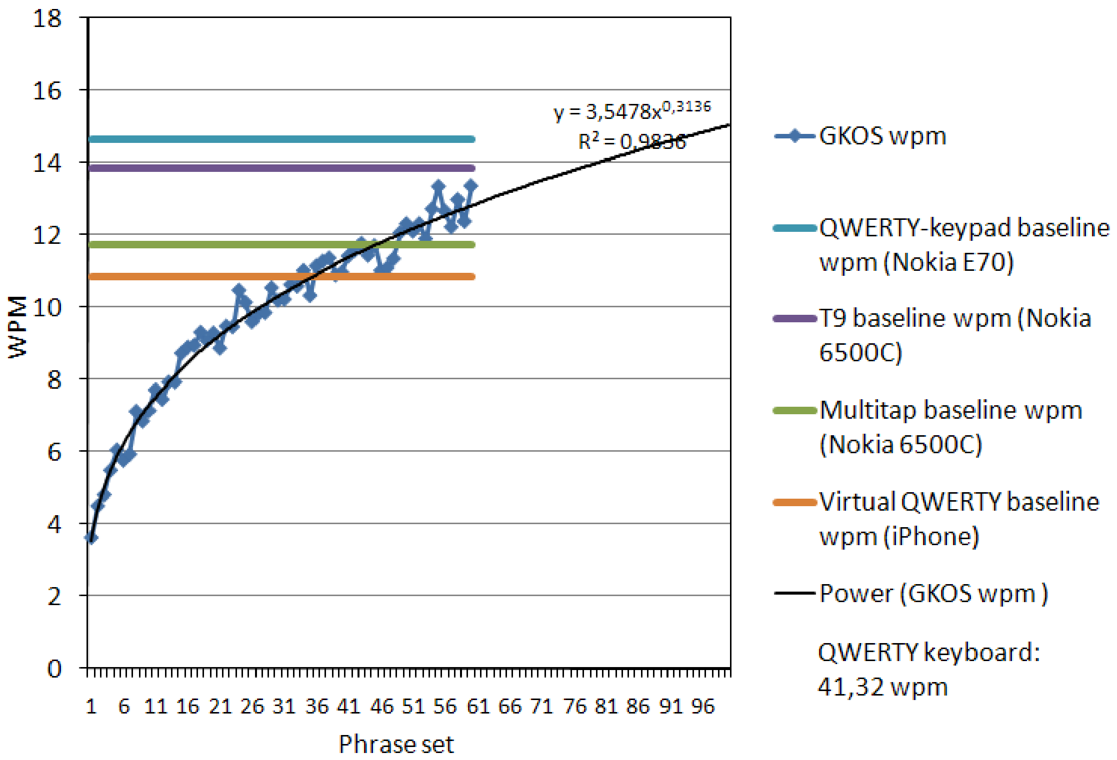

Figure 24: Mean figures consisting of participants' results for reference entry methods and GKOS. Best-fit power law of GKOS learning curve shows projected progress beyond the 60 phrase sets of measured data.

Figure 25 shows GKOS data for all ten participants on a per phrase set basis. Since the participants had varying knowledge and experience of mobile text entry methods and their results for the reference text entry methods varied strongly, it was expected that also the GKOS learning curves would have large variances. This was in fact the case. The WPM speed in the beginning of the experiment ranged from 1.94 WPM to 5.14 WPM. The last phrase set figures ranged from 8.58 WPM to 20.4 WPM. Participant 10 managed to type phrase set no. 53 (first phrase set on the eighth day) in 20.73 WPM. This was only topped by the pilot test participant whose performance in the 60th phrase set was 21.6 WPM.

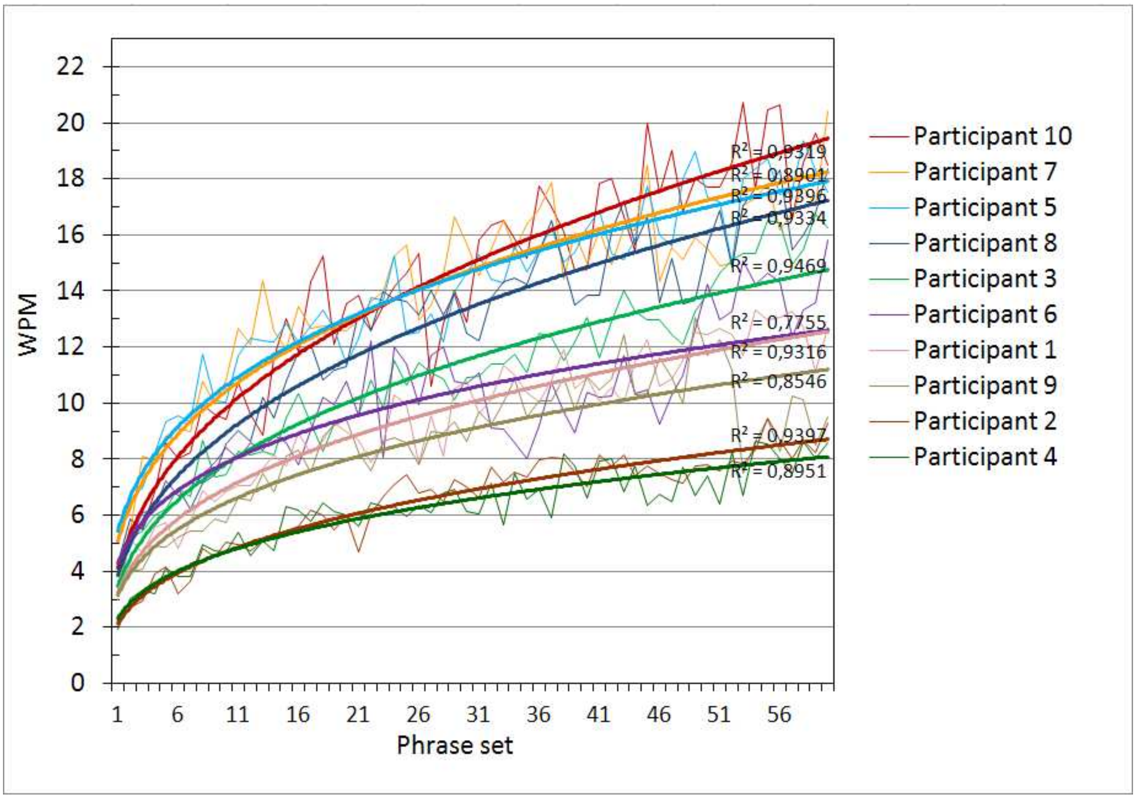

Figure 25: Participants' GKOS learning curves and power trendlines per phrase set basis.

The learning curves ranged from shallow to steep. Based on the learning curves, the participants' results can be divided into three categories: steep curve (participants 5, 7, 8, and 10), medium curve (1, 3, 6, and 9), and shallow curve (participants 2 and 4). In the end of the experiment, participants with the shallow curve reached 8.1-8.7 WPM GKOS text entry speed. Participants with the medium curve reached 11.2-14.8 WPM and participants in the steep curve category reached a comfortable 17.2-19.4 WPM typing speed.

Since every participant was typing the same number of phrase sets, the amount of time spent for learning the GKOS method differed. Out of the 10 participants, Participant 4 spent the most amount of time in typing the GKOS phrase sets (5 hours and 36 seconds). His GKOS WPM was 1.94 in the beginning and, according to a power trendline, 8.1 WPM in the end. Thus, during the learning period Participant 4 managed to increase his GKOS typing speed by 318 percent.

Participant 7, on the other hand, spent the least amount of time in typing the GKOS phrase sets. He started from 3.5 WPM but in the end, according to a power trendline, reached an 18.2 WPM text entry speed. For Participant 7, such a development (increasing GKOS text entry 420 percent) took only 2 hours, 10 minutes and 56 seconds of active typing with the GKOS keyboard.

Participant 5 was the most experienced mobile typist in our experiment. He was an experienced user of all the reference methods and his preferred mobile text entry method was QWERTY keypad (HTC Touch Pro). Figure 26 shows how his GKOS typing speed surpasses multi-tap and virtual QWERTY baseline results in the latter part of the GKOS learning phase. However, his QWERTY-keypad baseline result (35.76 WPM) shows how capable the novel QWERTY keypads can be in the hands of experienced typists.

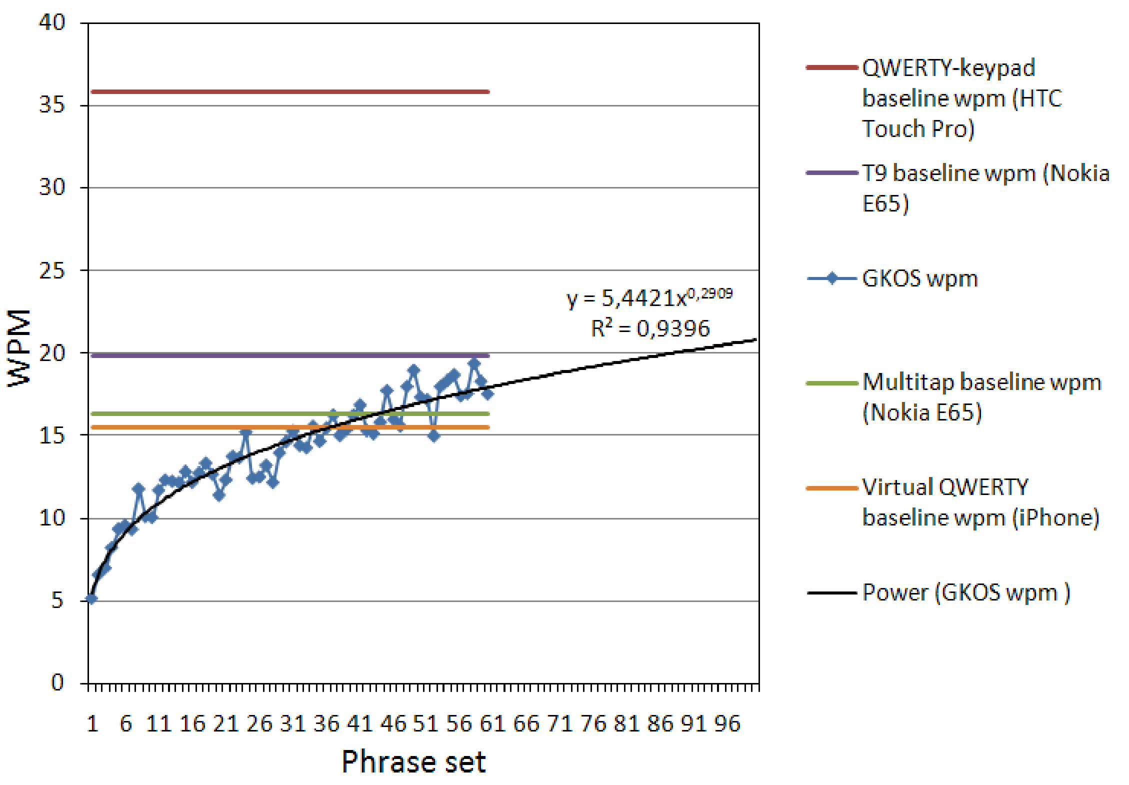

Figure 26: GKOS experiment results for Participant 5.

Participants' GKOS learning curves did not have many unexpected deviations. However, typing without looking at a character map was something that was encouraged for all participants during the GKOS introduction as it was likely to increase the typing speed. Participant 9 (Figure 27) had a drop in text entry speed for the last day because he tried to type without looking at the character map. For the same reason Participant 6's results were lower than expected on days 5 and 6. Some of the participants did not try to type without the character map at all and for others (excluding Participants 6 and 9) the transition away from the character map happened automatically and smoothly as they learned the GKOS key combinations.

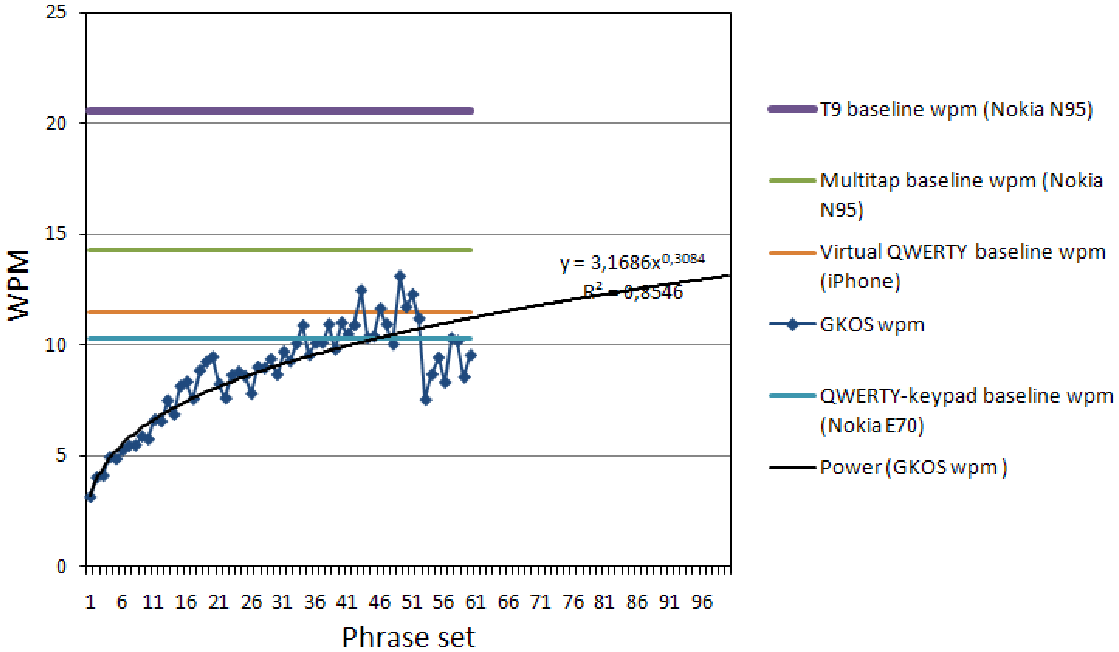

Figure 27: GKOS experiment results for Participant 9.

After the experiment 9 out of 10 participants said that their state of vitality affected the GKOS typing speed. Since the participants were typing the GKOS test phrases at home, there were no possibilities to monitor participants' alertness and make an analysis of its possible effects on typing speed and error rates.

Several participants also mentioned that the language affected their typing speed. All the participants were native Finns but the phrases were in English. Especially longer and unfamiliar words were said to decrease typing speed, since the participants had to check the spelling of such words many times to avoid errors. Actually, this inter-study comparability issue has been studied by Isokoski and Linden [2004], who conducted a small scale experiment for a similar setup that we had in our GKOS experiment: Finns writing English. Their goal was to verify that the text entry results between participants' native language and a foreign language differ. According to their experiment results, English language typing was 16% slower compared to Finnish. However, the researchers mention that there are several reasons why the 16% cannot be considered as a universal conversion factor. Nevertheless, it can be said that our GKOS experiment text entry performance would have been slightly better, if the participants had been native English speakers or had the phrases been translated in Finnish.

6.2. Errors and difficult characters

As already mentioned in Section 5.4.2, the software used in the experiment was not quite perfect for text entry experiment purposes, as it lacks some preferred features such as keyboard event logging. Therefore, the data about errors is very limited.

The TypingMaster Typing Test software only counted the number of mistyped words in a phrase set. Word length and number of errors within the word had no effect on how the software determined the number of errors. For instance, word "the" mistyped "teh" or word "confidential" mistyped "cfonffidenoall" both counted as one mistyped word.

The GKOS participants mistyped a total of 351 words in 3000 sentences. In other words, participants mistyped 0.59 words per phrase set (five sentences). Participants' combined number of mistyped words per phrase set is shown in Figure 28. The number of errors per phrase set ranged from 0 to 13. The number of errors seems to increase slightly in the latter part of the experiment, since the number of errors for the first half is 152, and 199 for the latter half. Several participants mentioned that a lot of the errors happened when they pressed a space key and only after that they noticed an error. As already mentioned in Section 5.4.2 a space key indicates for the program that a word is finalized and cannot be modified any more.

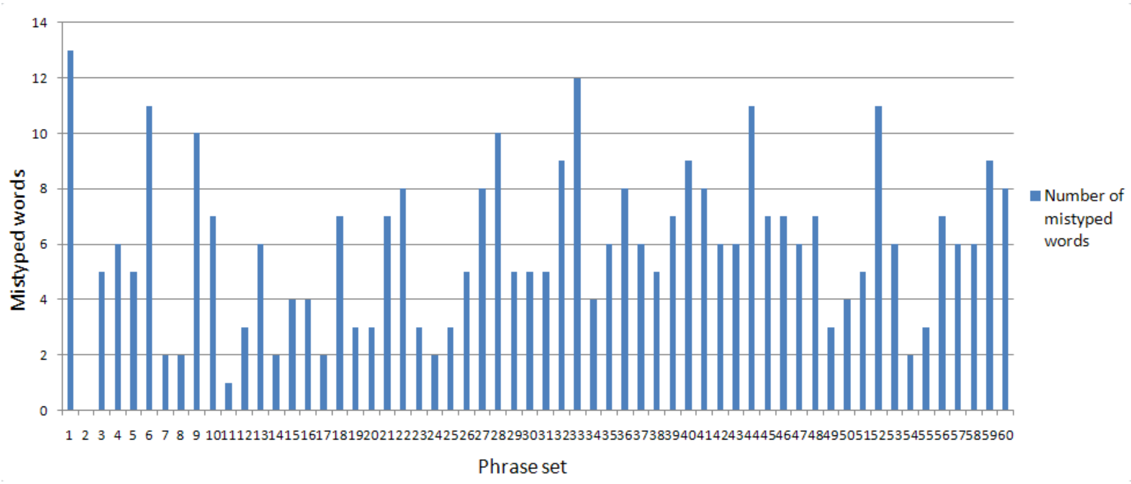

Figure 28: GKOS participants' combined number of mistyped words per phrase set.

After the experiment the participants were asked if some of the characters were more difficult to produce than others. More than one participant mentioned letters H, I, J, O, P, Q, and R. Letters G, L, and U were mentioned once.

After the experiment, 6 out of 10 participants felt that they produced more errors with GKOS than with their current mobile text entry method. Since we did not conduct a comparison test, there is no data available to investigate if participants' assumptions of the error rates are correct. However, based on the participants' answers, they did not feel that the test device or software was the cause for the errors. In fact, 8 out of 10 participants said that GKOS typing errors were due to pressing a wrong key combination.

6.3. Post-experiment questionnaire results

After the GKOS learning phase was over, the participants answered a short post-experiment questionnaire. The questions were in Finnish (Appendix 2), and the first part of the questionnaire contained 13 statements. We used a five-level Likert scale for the answers [Likert, 1932]. Some of the statements were related to typing errors and the results were already mentioned in Section 6.2. The remaining statements and other questions are reviewed in this section (Table 2).

In general, the participants gave good reviews for the GKOS method. All the participants thought that the GKOS method was fascinating to learn. They also felt unanimous that it was rewarding to learn the GKOS method. All but one of the participants found the test device and software to be easy to use. Participant 7 complained that it was distracting that the test phrases were not in correct order in the test software's phrase list. Participant 7 also mentioned that it was annoying that a finished word (indicated by typing a space) was not allowed to be erased, and thus created more mistyped words.

8 out of 10 participants thought that it was easy to learn the GKOS method, and that the GKOS key combinations seemed logical. All the participants also praised the simplified GKOS character map that was used in the experiment. We also asked the participants when they felt that the character map was no longer needed to type the sentences. Two of the participants said that they did not need the map after the day 1 phrases were completed. One participant felt confident about the key combinations after day 2, another after day 3, and yet another after day 4. 5 out of 10 participants felt that they still needed the character map after day 4, and even after day 8, which was the final day of the experiment. After the post-experiment questionnaire, we decided to conduct a small ad-hoc test for those five participants who felt they still needed the character map for typing. The participants typed one more randomly chosen phrase set without the help of a character map. Everyone managed to type the phrase set without problems. Since the additional ad-hoc phrase set performance was not recorded, we cannot say whether the text entry speed was faster or slower compared to those participants' text entry performance during the final phrase sets. Nevertheless, it was shown that also the participants, who thought they still needed the character map actually did not need one.

The GKOS typing at the end of the experiment was dividing participant's opinions. 6 out of 10 thought that typing was effortless, but 4 thought that it was not. For instance, participant 5 thought that at times the keyboard seemed "sticky", meaning that there seemed to be some problems detecting the key presses. Participant 5 mentioned that the reason for such performance might have been his laptop, in which he had attached the GKOS text device keyboard to perform the GKOS experiment test phrases. Participant 8 said that he still had to focus a lot when writing with GKOS so typing did not feel effortless.

The participants were also asked questions about the interest in replacing their current mobile text entry method with GKOS, if it was implemented to a mobile phone in an ergonomic way, for instance, as illustrated in Figure 13 in Section 4.3. Most likely these questions were a little bit too vague, and therefore the answers ranged from "fully agree" to partially disagree. However, the participants showed interest towards the concept device.

Statement	Fully agree	Partially agree	Do not know	Partially disagree	Fully disagree
It was fascinating to learn the GKOS method.	7	3	0	0	0
It was easy to learn the GKOS method.	2	6	1	1	0
It was rewarding to learn the GKOS method.	2	8	0	0	0
GKOS key combinations seemed logical.	1	7	1	1	0
It was easy to use both GKOS test device and the typing test software.	6	3	0	1	0
At the end of the experiment GKOS typing was effortless.	1	5	0	3	1
GKOS character map was easy to interpret.	2	8	0	0	0
I would be interested to replace my current mobile text entry method with GKOS, if text entry would be ergonomic and it would not affect the physical size or price of the phone.	1	2	3	4	0
I would be interested to use GKOS text entry method with a phone, if it was implemented as in the picture below (keys in the back of the device, touch screen in front) (see Appendix 2).	1	5	3	1	0

Table 2: A part of the post-experiment questionnaire statements and answers (green color = two or more agree, red color = two or more disagree, grey color = two or more do not know).

After the statements, the participants were asked to put the mobile text entry methods in order based on their typing speed performance in the experiment. For the GKOS method, the participants were told to consider the typing speed level they had reached by the end of the experiment. Since the baseline tests for the reference methods were measured in the very beginning of the experiment, most of the participants had only a "gut feeling" about how those tests had went. On the other hand, the participants had quite a good idea about their GKOS performance level.

The results show that evaluating the text entry performance levels of the mobile text entry methods was not an easy task: None of the participants were able to put the methods in correct order. Participant's evaluations are listed in Table 3. Each participant put the methods in order from 1 to 5 (1 = fastest text entry speed result, 5 = slowest result). The numbers in bold is the correct order based on the GKOS experiment results and baseline test results.

Table 3 shows that the participants were underestimating their GKOS typing speed against the other methods. Only two participants placed GKOS correctly in relation to the other methods. The remaining eight participants thought that their GKOS typing was slower than in reality compared to the other methods. When all participants' text entry method estimation results are added together, GKOS is the slowest of all the methods (36 "points"). However, when we look at the results based on our baseline measurements and experiment results, on average, GKOS is actually the fastest of the five methods (22 "points"). Naturally such an evaluation is not very sensible, since it was only the GKOS method that the participants were rehearsing during an eight day learning period. The results shown in Table 3 are especially unfavorable for QWERTY keypad and virtual keyboard methods, since many of our GKOS participants were trying those methods for the first time in our experiment. Most likely allowing a slightly longer practice period for those two methods before measuring the baseline speeds, would have already made a difference in the results.

	Multi-tap		T9		QWERTY keypad		Virtual keyboard		GKOS (end of exp.)	
Participant 1	3	**5**	1	**1**	5	**4**	4	**3**	2	**2**
Participant 2	5	**5**	1	**4**	3	**1**	2	**3**	4	**2**
Participant 3	2	**3**	1	**4**	5	**1**	4	**5**	3	**2**
Participant 4	2	**4**	3	**2**	1	**5**	4	**3**	5	**1**
Participant 5	5	**4**	2	**2**	1	**1**	4	**5**	3	**3**
Participant 6	1	**2**	4	**4**	2	**1**	3	**5**	5	**3**
Participant 7	5	**5**	3	**4**	2	**2**	1	**1**	4	**3**
Participant 8	4	**3**	5	**4**	1	**2**	3	**5**	2	**1**
Participant 9	3	**2**	1	**4**	2	**5**	4	**3**	5	**4**
Participant 10	2	**2**	1	**4**	4	**3**	5	**5**	3	**1**
Total ”points” (less is better)	32	**35**	22	**27**	26	**28**	34	**38**	36	**22**
Rank	4	**4**	1	**2**	2	**3**	3	**5**	5	**1**

Table 3: GKOS participants' evaluation of their text entry performance levels for various mobile text entry methods. The grey numbers on the left column are participants' estimations and the bolded black numbers on the right column are the actual rank of the method based on text entry measurements.

7. Discussion and future work

In this chapter we will discuss the results of our GKOS experiment and how the results compare to some of the previous experiments conducted for chorded keyboards. The chapter is divided into four sections. In Section 7.1 we focus on text entry speed development, and in Section 7.2 we discuss characters that caused difficulties for the participants in the experiment. Three potential use contexts are presented in Section 7.3. We claim that interaction and communication could be enhanced on the described situations if GKOS method is implemented. In the fourth section we present some recommendations related to future research of the GKOS method.

7.1. Text entry speed development

We set up four goals for our experiment and presented them as questions. The second question was: how rapidly does GKOS typing speed increase in the early phase of learning?

The mean speed for GKOS was 3.4 WPM in the beginning and 12.8 WPM in the end, meaning that GKOS participants had an overall improvement of 277 percent between the first and last phrase set. Four participants reached a comfortable 17.2-19.4 WPM typing speed at the end of the experiment.

Since participants' results differed a lot from each other (both for reference methods and for GKOS), there is not much point in drawing strong conclusions from the combined results. However, based on both our results and previous findings and records of multi-tap text entry speed [James and Reischel, 2001; MacKenzie et al., 2001; Widgor and Balakrishnan, 2003], it can be said that GKOS method surpasses multi-tap text entry speed after a short learning period. To be more specific, 8 out of 10 participants overcame multi-tap with GKOS by the end of the experiment. Thus, our experiment results are in line with GKOS inventor's claim "after a small amount of practice, the typing speed exceeds that of the GSM number pad method" (multi-tap).

Based on the results of our small GKOS experiment, GKOS inventor's second claim "*It is easy to reach a speed of 20 WPM with some practicing*" does not seem like an overstatement. However, such a typing speed might not be easy to achieve for persons who do not type fast with any other text entry device. For instance in our experiment Participant 4's QWERTY typing was below 20 WPM and he had significant experience only in the multi-tap method (had been using over a year). In addition, it is worth to note that Participant 4 claimed to write only a few words per day with his preferred text entry method (multi-tap, bolded line in Figure 29). It is likely that a lack of typing experience in general affected Participant 4's GKOS results (8.1 WPM in the end of experiment). However, during the learning period, Participant 4 managed to increase his GKOS typing speed by 318 percent.

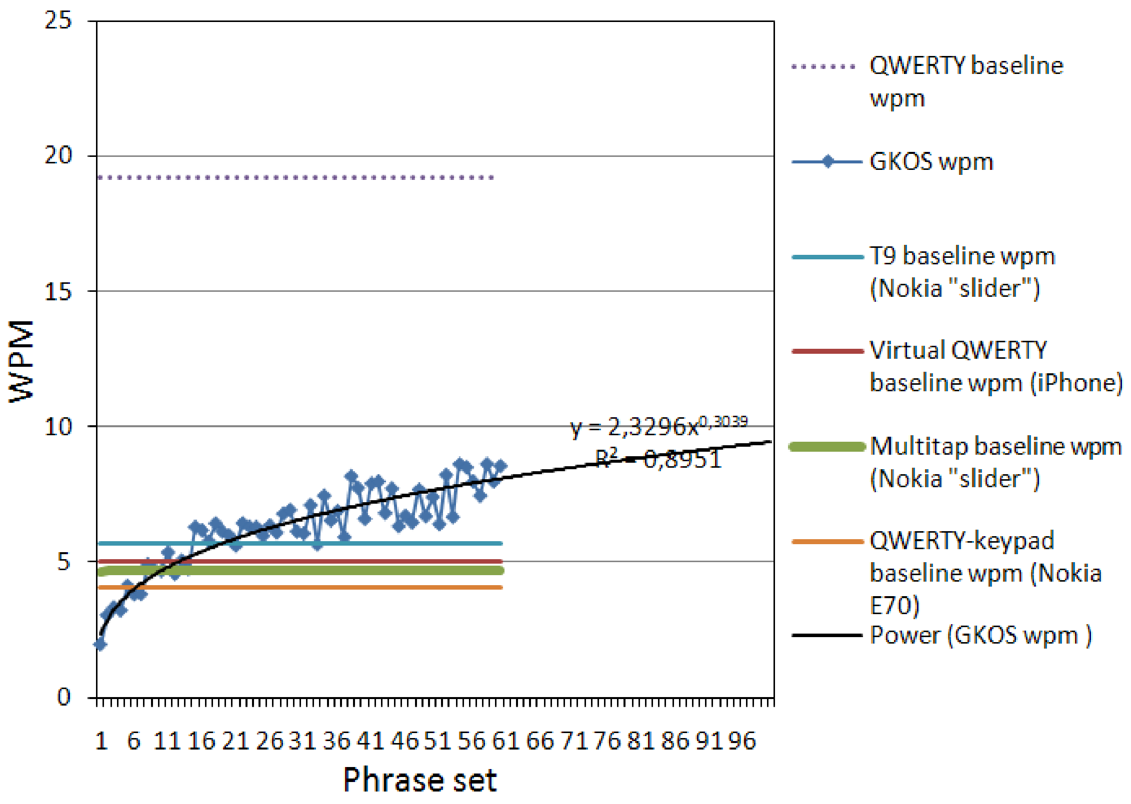

Figure 29: GKOS experiment results for Participant 4.

7.1.1. GKOS, ChordTap, and Twiddler

Since it is common that text entry experiment setups differ from each other, it is not easy to compare the text entry methods based on achieved results. For instance, the earlier discussed ChordTap experiment by Widgor and Balakrishnan [2004] had a total of 16 blocks (phrase sets) divided in two sessions. In each block the participants typed 20 phrases. This means that every participant typed a total of 320 phrases. In the beginning, the mean text entry speed for ChordTap was 8.46 WPM, which is significantly higher than our GKOS experiment's 3.4 WPM. ChordTap users had an overall improvement of 90% between the first and last blocks. Thus, the mean speed in the end was 16.06 WPM. It is worth noting that although ChordTap is a chording method, it also enables hunt-and-peck typing, since ChordTap is utilizing the standard 12-key numeric keypad present on many mobile phones.

Another chorded keyboard study already discussed in Chapter 3 was a longitudinal study by Lyons et al. [2004] of novice users' learning rates on the Twiddler. At the end of the experiment (session 20) the mean Twiddler typing speed was 26.2 WPM. The researchers also noted that Twiddler typing performance would still increase after 20 sessions. If we only focus on the final WPM figures, it seems that Twiddler is clearly a superior chording technique compared to GKOS. However, there are three reasons why the results of the Twiddler experiment are not directly comparable with the results of our GKOS experiment.

Firstly, the experiment setups were different. In the Twiddler experiment the time of the learning period was fixed (20 x 20 minutes), whereas our GKOS experiment and Widgor’s and Balakrishnan’s [2004] ChordTap experiment had a fixed number of phrase sets that were typed by each participant. For instance, in our GKOS experiment the participants’ learning period lasted from 134 minutes up to 300 minutes. In the Twiddler experiment every participant typed for 400 minutes.

Secondly, there was a difference in the participants’ QWERTY typing skills at the start of the experiments. The Twiddler experiment participants’ QWERTY WPM figures ranged from 54.1 WPM to 113.9 WPM. In GKOS experiment similar figures ranged from 16 WPM to 72 WPM. In other words, the participants in Twiddler experiment were either advanced or expert QWERTY typists, whereas the GKOS participants ranged from novice typists to advanced typists. Lyons et al. [2004] also noticed a strong correlation between the participants’ QWERTY WPM and Twiddler chording WPM (as well as QWERTY WPM and Twiddler multi-tap WPM). They suggest that it might be possible to predict chording rates from QWERTY text entry rates. The results from our GKOS experiment do not reinforce such prediction (Table 4). However, it should be remembered that the QWERTY baseline figures in GKOS experiment were formed based on the typing performance of only ten phrases and therefore the accuracy of the QWERTY WPM rates presented in Table 4 are questionable. Nevertheless, it is likely that the GKOS text entry development mean figures would have been higher, had the participants been advanced or expert QWERTY typists as in the discussed Twiddler experiment.

QWERTY WPM	GKOS WPM	GKOS (%)
72	17.9	24.9
65.1	18.3	28.1
65.1	12.6	19.4
43.2	17.3	40.0
39.8	14.8	37.2
32.9	19.4	59.0
32.2	11.2	34.8
27.7	12.6	45.5
19.2	8.1	42.2
16	8.7	54.4

Table 4: GKOS text entry rates as a function of QWERTY speed.

Thirdly, different compensation schemes may have affected participant performance. In Twiddler experiment every participant was informed about the significant time commitment required for the study and they were compensated for their participation calculated at the rate of $1 x WPM x Accuracy over the entire session, with a minimum of $8 per session [Lyons et al. 2004]. In our GKOS experiment the participants were only given a gift worth of €15 regardless of the participants' performance.

7.1.2. Additional remarks about the GKOS text entry results

There are several factors that should be taken into account when forming an opinion about the capabilities of the GKOS method based on our experiment results.

Firstly, the test results should not be looked at very strictly, since our test device differed a lot from the GKOS concept devices that the creator of GKOS has developed. Secondly, we did not put an effort in optimizing the dwell time (the time a key pressed) and the flight time (the time between "key down" and the next "key down" and the time between "key up" and the next "key up") for our GKOS test device. Thirdly, the participants were not typing the test phrases in their native language, which most likely decreased the overall text entry performance.

7.2. Difficult characters

As already mentioned in the previous chapter, the software we used in our GKOS experiment did not log individual key presses and therefore the data about errors is very limited. However, we gained some additional information about the difficult key combinations from the post-questionnaire answers.

After the experiment the participants were asked if some of the characters were more difficult to produce than others. More than one participant mentioned letters H, I, J, O, P, Q, and R. Letters G, L, and U were mentioned once. This was somewhat expected, since letters H, I, J, and P, Q, R all require the user to press three keys simultaneously. On the other hand, also letters L, M, N, T, U, V, and X, Y, Z are produced with three simultaneous key presses.

So why were H, I, J, P, Q, and R considered more difficult? The reasons for this could be related to the anatomy of fingers as well as letter frequencies in the English language. The letters that were considered more difficult to produce require that the user uses middle finger and ring finger on one hand and either index, middle, or ring finger on the other hand. Actually, for letters H and P ring fingers from both hands are used. The reason why we are focusing on ring fingers is because the ring finger is considered as the weakest of the fingers on the hand as it shares a flexor muscle with the middle and little fingers. It is also the only finger that cannot be fully extended independently by the majority of people. So, the difference in producing letters L, M, N, T, U, or V is that the user presses two keys with middle and index fingers (no ring finger!) on one hand, and either index, middle, or ring finger on the other hand.

Letters X, Y, and Z also require the user to use a ring finger and an index finger. However, the participants did not report that these letters were difficult to produce. The reason for this could be in letter frequency. According to a statistical analysis, letter Y is uncommon in the English language and X and Z are very uncommon [Lewand, 2000]. So it could be that letters X, Y, and Z were difficult to produce, but the participants did not mention them since those letters came up so few times in the GKOS experiment phrase sets.

7.3. Interesting use contexts for the GKOS method

Like in the case of other chorded keyboard methods, also the GKOS method is likely to have serious trouble penetrating its way into the mobile phone market. The dominance of the 12-key numeric keypad and the provided text entry methods (multi-tap and T9) can be considered almost as strong standard in mobile phones as QWERTY keyboards are in personal computers. In the smart phone segment, familiar QWERTY layout is successfully present both in QWERTY keypads and in virtual keyboards. Since the sales of smart phones are increasing, we can presume that the consumers are content with these text entry methods. Such presumption can be backed up with text entry experiments: results show that text entry rates for QWERTY keypad and virtual keyboard implementations are in the range of 30-40 WPM.

The key feature that separates a 6-key GKOS method from current common mobile text entry methods is touch typing. In the GKOS method, the fingers are always placed on the six keys enabling the user to interact and communicate without the need to hunt and peck for the characters. Since GKOS frees the user to observe the surroundings during interaction, it brings new possibilities to introduce key-based text entry on situations where it has not been possible before. In this section we introduce three "use contexts" or "situations of use" that would benefit from an implementation of GKOS.

7.3.1. GKOS remote control for home theater personal computer (HTPC)

Lately, television manufacturers have introduced popular web service implementations on their new TV sets. However, most of the current products are equipped with standard remote controls that provide only slow text input capabilities.

A home theater personal computer (HTPC) enables a more versatile Internet and media consumption experience in the living room. Also in this case a good experience requires a proper input device, and since HTPC is a PC, there are already alternatives for input devices.

A standard wireless QWERTY keyboard and a wireless mouse provide a familiar feel, but might not be the most aesthetic choice for the living room. A bulky keyboard is also somewhat difficult to use in "laid back" situations, such as lying on a sofa. Using a wireless mouse is even harder.

There are products that have been especially designed for "laid back" situations, like Logitech's diNovo Mini [Logitech, 2010]. Based on discussion forum comments, some consumers feel that diNovo Mini's €120 price tag is too high. Another commercial alternative is EFO's iPazzPort, which is a Bluetooth wireless handheld keyboard (Figure 30) that combines a touchpad and a QWERTY keyboard including function and media keys that were missing in the 1st generation of iPazzPort [EFO, 2010].

Figure 30: EFO's iPazzPort - Bluetooth wireless handheld keyboard [EFO, 2010].

Even though there are some handheld controllers designed for HTPC use, a GKOS device illustrated in Figure 31 could have potential in the emerging market of connected TVs and living room media centers.

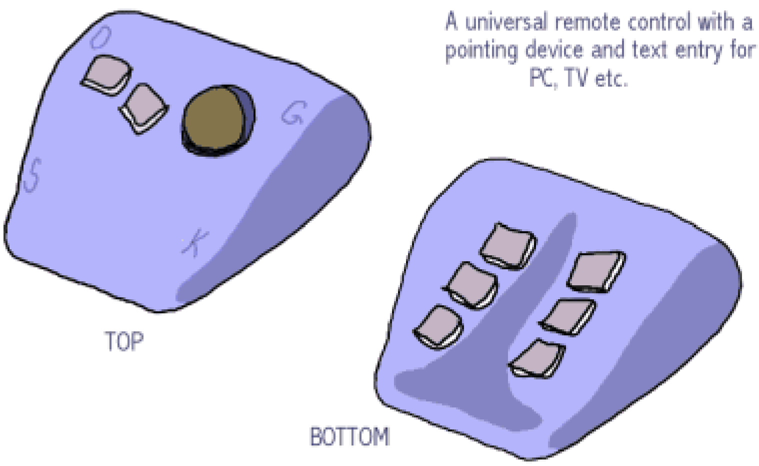

Figure 31: A sketch of a GKOS remote control combining a pointing device and a GKOS text entry method [GKOS-1, 2010].

It is also possible that smart phones and tablet computers like Apple's iPad, will provide the remote control possibilities for the users. There are already some applications available for smart phones, like Mobile Air Mouse for the iPhone, that allow the user to fully control a PC with the smart phone over a Bluetooth or WiFi. There are also open source projects and research papers available that concentrate on the field of HTPCs and mobile devices [Maia et al. 2009].

7.3.2. GKOS as a controller for an in-vehicle infotainment system (IVIS)

As discussed in the previous section, GKOS has potential in the world of HTPCs, but we see that GKOS as an in-vehicle infotainment system (IVIS) controller would be even more beneficial for the manufacturers and end-users. IVIS provides the user, either a driver or a passenger, relevant information, entertainment, and communication possibilities during a journey. IVIS often incorporates a mobile computer with a touch screen. The system can include a media player, a navigator, a weather forecast service, and other services.

If GKOS were implemented for IVIS as illustrated in Figure 32, the driver would be able to operate IVIS without taking his or her eyes of the road. Text entry and infotainment system controls would be inserted behind the steering wheel, and this would enable also communication service integration to the system. Naturally operation of IVIS causes more distraction for the driver, with or without GKOS implementation. However, we believe that GKOS would cause less distraction for experienced typists than current IVIS controllers (virtual QWERTY on a touch screen).

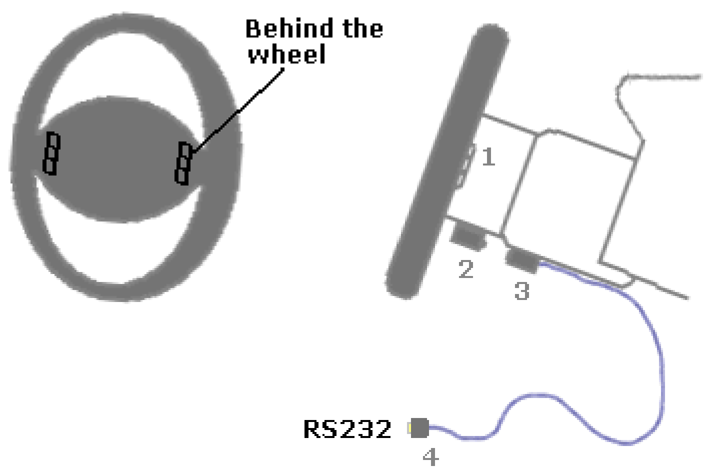

Figure 32: IVIS GKOS controller sketch [GKOS-1, 2010].

IVIS interaction and especially speech-based interaction has been studied a lot. Speech-based interaction has been considered as a suitable interaction method in in-vehicle situations, because it is less distractive than some other methods [Maciej and Vollrath, 2009]. However, background noise in the vehicle can still cause problems in interaction. A study by Maciej and Vollrath [2009] showed that speech-based interaction is a desirable interaction method for the car of the future, but it is still causing too much distraction during driving.

7.3.3. GKOS gloves, mobile computer, and a head-mounted display

A third interesting use context for the GKOS method is looking a little bit further into the future. We predict that when light-weight head-mounted displays wirelessly connected to mobile computing devices become more popular as consumer products, there is a need for new interaction methods. **Error! Reference source not found.** presents a concept setup for a future of mobile computing that includes GKOS gloves equipped with pressure sensors, a mobile computing device, and a sunglasses-sized head-mounted display. All three components would be connected to each other wirelessly.

The GKOS gloves could be used to interact with the device by pressing fingers against any surface. This would enable the user to constantly observe the surroundings while having a conversation or some other online activity.

Figure 33: Future of mobile computing combining GKOS gloves, a mobile computer and head-mounted display (images from Vuzix.com and Xenmobile.com).

Even though pressure-sensitive GKOS gloves are currently just an interesting concept to consider, Brewster and Hughes [2009] have already performed an experiment that studied pressure-based text entry for mobile devices. The researchers were investigating if pressure could be used to improve input performance when entering mixed-case text. The results were promising and indicate that pressure input can perform better than a standard shift-key design.

Skinput, presented by Harrison et al. [2010], is another interesting technology that relates to our GKOS concept presented in Figure 33. Skinput enables the skin to be used as an input surface. Harrison et al. analyzed the differences in acoustic energy that is transmitted through the human body when a finger taps certain parts of an arm or a hand.

7.4. Recommendations for future research of the GKOS method

The main goal of this thesis was to find out about the overall learnability of the GKOS method among novice users. We wanted to have an idea about the understandability of the character map and about the learning rate of the basic key combinations. We were also interested to know how much typing speed would improve in the early phases of learning, and how people with varying knowledge of mobile typing methods would perform with our GKOS test device.

We were quite happy with the achieved results. However, there were several factors that hindered the value of the results. For instance, the GKOS test devices worked well in technical sense, but in the future experiments the test device should better resemble some of the concept devices illustrated in GKOS.com. GKOS test devices modified from QWERTY keyboards could of course be present also in the follow-up experiments, but they should not be the only GKOS devices used in the experiment. Actually, it might bring extra value to the results if a comparison study that includes several GKOS concept devices is conducted.

After our GKOS experiment participants had done their part, we were curious to know how well an advanced typist would be able to perform a set of test phrases with various GKOS devices. We asked the GKOS inventor to type eight phrase sets, which meant a day’s exercise in our experiment schedule. Figure 34 shows that there were significant differences in typing speed between the methods. Since Mr. Tiainen had not been typing with any of the GKOS devices in a while before the short experiment, we can see a typing skill development also in his results for each of the GKOS methods.

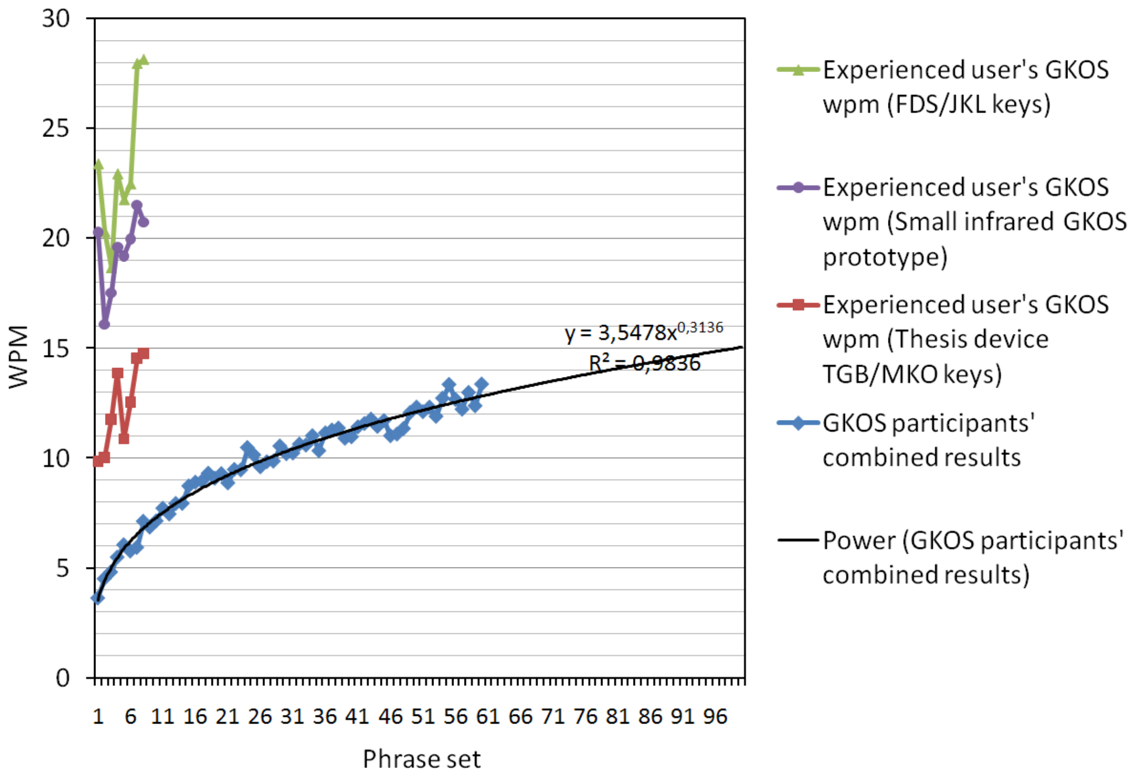

Figure 34: A comparison of experienced user's GKOS test results and novice users' combined GKOS experiment results.

A follow-up GKOS experiment should be a longitudinal comparison study, where GKOS is compared to one or more of the following: T9, QWERTY keypad, virtual keypad or Twiddler.

MacKenzie et al. [2001] suggest that when discussing text entry skill acquisition, the learning should be divided into three phases. Based on their comparison study results of LetterWise and multi-tap, they came up with the terms "discovery phase", "motor reflex acquisition phase" and "Terminal (Fitts's law) phase". The discovery phase lasts only hundreds of keystrokes, the motor reflex acquisition phase thousands of keystrokes, and in terminal phase "all reflexes are learned, and entry speed is determined by keypad geometry and the frequency with which pairs of keys are operated in succession".

In our GKOS experiment, the participants managed to reach "the motor reflex acquisition phase". If our experiment would have been longer, we would have been able to predict the GKOS typing skill development beyond measured data more accurately (Figure 35).

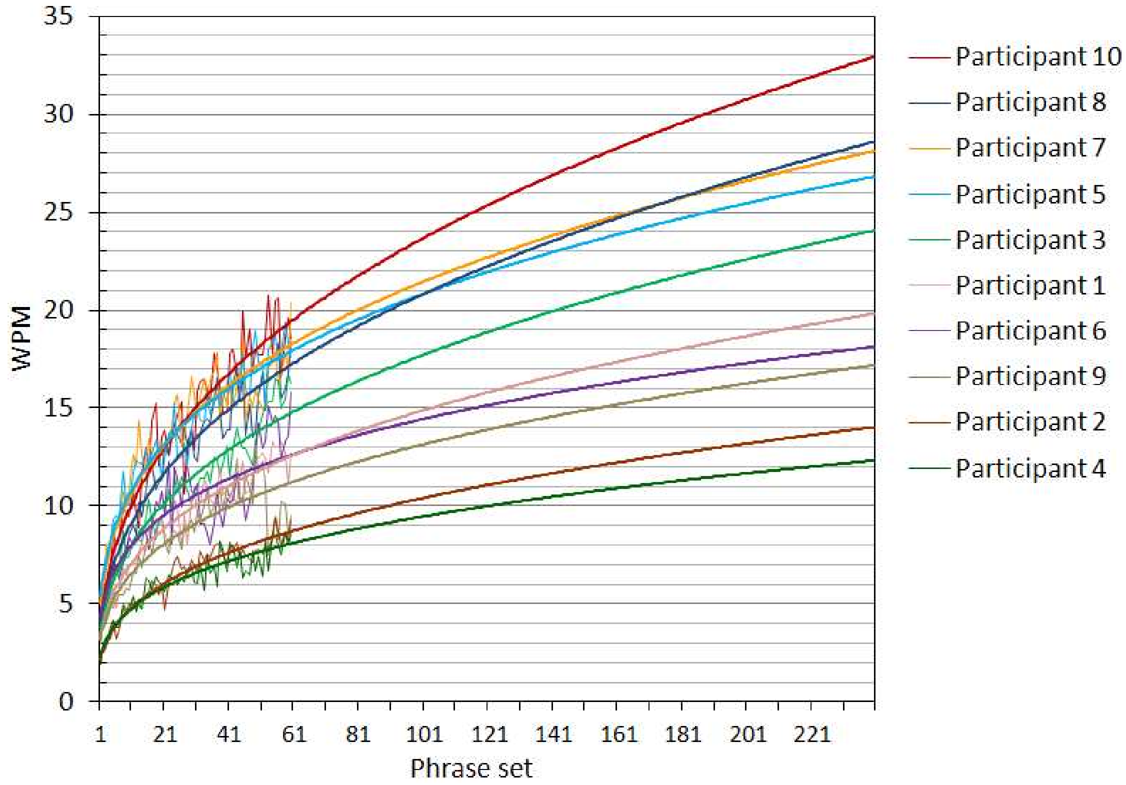

Figure 35: Participants' GKOS learning curves and power trendlines per phrase set basis. Trendlines show participants projected progress beyond the 60 phrase sets of measured data.

It would be beneficial to select the participants from a narrow age group and with similar typing skills. In fact, it might not be a bad idea to create a similar experiment setup as Lyons et al. [2004] had in their Twiddler study. This would help to properly evaluate GKOS against a chorded keyboard method that has been praised for its high WPM rates.

The software for collecting and analyzing participants' results should provide proper key logging so that GKOS error rates and overall performance can be properly investigated.

8. Conclusion

This thesis investigated the learnability and acceptance of the GKOS text entry method among novice users. The experiment was conducted for 10 participants and the results were promising. The predefined four main questions were answered.

First question: how easy is it to learn the basic key combinations of GKOS in order to type full sentences? According to our post-experiment questionnaire, it seems to be relatively easy. Every participant thought that the character map was easy to interpret, and 8 out of 10 participants thought that the GKOS key combinations were logical and that the method was easy to learn.

Second question: how rapidly does GKOS typing speed increase in the early phase of learning? The mean speed for GKOS was 3.4 in the beginning and 12.8 WPM in the end, meaning that GKOS participants had an overall improvement of 277 percent between the first and last phrase set. GKOS text entry is easy to learn both for experienced and inexperienced mobile typists. Four participants reached a comfortable 17.2-19.4 WPM typing speed at the end of the experiment.

Third question: how does GKOS compare to the other common mobile text entry methods in terms of typing speed? In our experiment participants' combined GKOS mean speed (12.8 WPM) surpassed both the rough average multi-tap speed (10 WPM) based on earlier text entry studies and the mean multi-tap speed calculated in the beginning of our experiment (11.73 WPM). When looking at individual results, 8 out of 10 participants overcame multi-tap with GKOS by the end of the experiment. In order to compare GKOS to other reference methods (T9, QWERTY keypad and virtual keyboard) a longitudinal comparison study should be conducted with proper GKOS devices that better resemble the GKOS concept devices presented in GKOS.com.

Fourth question: what kind of reception does the GKOS method get from mobile users with alternating experience of mobile text entry systems? GKOS received very good reviews both from inexperienced and experienced mobile users that participated in our experiment. However, the more experienced participants did not see GKOS as a potential competitor for QWERTY keypads and virtual keyboards in the smart phone market.

Most likely, Multi-tap and T9 will remain the dominant typing methods for basic mobile phones for many years to come. In the smart phone category, QWERTY keypads and virtual QWERTY will probably retain their popularity.

One of the biggest challenges for chorded keyboards is the additional training that is required before the user learns the correct key combinations and is able to produce desired letters. It takes some more time before text entry speed reaches an adequate level. Despite these issues, the GKOS method and GKOS prototype devices should be further studied, as they have the potential to enable interaction and communication possibilities in new mobile contexts and situations. We estimate that these are the best possibilities for the GKOS method to gain popularity and wide-scale acceptance in the world of ever-increasing, diverse, and ubiquitous mobile communication.

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Appendix 1

GKOS Pre-experiment questionnaire (in Finnish)

TAUSTATIETOLOMAKE

TAUSTATIEDOT

Ikä: ______________ **Sukupuoli:** [ ] Mies [ ] Nainen

Ammatti:
[ ] Ylempi toimihenkilö tai yrittäjä
[ ] Alempi toimihenkilö tai työntekijä
[ ] Opiskelija tai koululainen
[ ] Eläkeläinen
[ ] Työtön tai virkavapaalla

Koulutus:
[ ] Peruskoulu
[ ] Ammattikoulu
[ ] Lukio
[ ] Alempi korkeakoulututkinto
[ ] Ylempi korkeakoulututkinto

MATKAPUHELINTEN TEKSTINSYÖTTÖMENETELMÄT

Kokemuksesi Multi-tap-tekstinsyöttömenetelmästä (perinteinen matkapuhelimen tekstinsyöttömenetelmä)
[ ] Olen käyttänyt yli vuoden
[ ] Olen käyttänyt muutamasta kuukaudesta vuoteen
[ ] Olen kokeillut joskus
[ ] Ei kokemusta

Esimerkki laitteesta, jossa käytössä multitap- ja ennustava tekstinsyöttömenetelmä

Kokemuksesi ennustavasta tekstinsyöttömenetelmästä (T9)
[ ] Olen käyttänyt yli vuoden
[ ] Olen käyttänyt muutamasta kuukaudesta vuoteen
[ ] Olen kokeillut joskus
[ ] Ei kokemusta

Kokemuksesi QWERTY keypad -tekstinsyöttömenetelmästä (jokaiselle kirjaimelle oma painike)
[ ] Olen käyttänyt yli vuoden
[ ] Olen käyttänyt muutamasta kuukaudesta vuoteen
[ ] Olen kokeillut joskus
[ ] Ei kokemusta

Esimerkki laitteesta, jossa käytössä QWERTY keypad -tekstinsyöttömenetelmä

Kokemuksesi virtual keyboard -tekstinsyöttömenetelmästä (painikkeet kosketusnäytössä)
[ ] Olen käyttänyt yli vuoden
[ ] Olen käyttänyt muutamasta kuukaudesta vuoteen
[ ] Olen kokeillut joskus
[ ] Ei kokemusta

Esimerkki laitteesta, jossa käytössä Virtual keyboard -tekstinsyöttömenetelmä

Ensisijainen matkapuhelimen tekstinsyöttömenetelmäsi tällä hetkellä
[ ] Multi-tap [ ] QWERTY-keypad
[ ] Ennustava tekstinsyöttö [ ] Virtual-keypad [ ] Joku muu, mikä:______________________

KÄÄNNÄ!

Keskimääräinen tekstinsyöttömääräsi matkapuhelimella (tekstiviestit, sähköpostiviestit, verkkoselaus, ym.)
[ ] Muutama sana päivässä [ ] Kymmenen sanaa päivässä [ ] Kymmeniä sanoja päivässä
[ ] Satoja sanoja päivässä [ ] Yli tuhat sanaa päivässä

Vaikuttaako käyttämäsi tekstinsyöttömenetelmän tehottomuus matkapuhelimella tuottamasi tekstin määrään?
Kyllä [ ] Ei [ ] En osaa sanoa [ ]

Tutkimuksen tekijä täyttää:

Testihenkilö nro:________

QWERTY

Aika:__________________ Virheet:__________________

Multitap

Aika:__________________ Virheet:__________________

T9

Aika:__________________ Virheet:__________________

QWERTY-keypad

Aika:__________________ Virheet:__________________

Virtual-keypad

Aika:__________________ Virheet:__________________

Muita huomioita:

Appendix 2

GKOS Post-experiment questionnaire (in Finnish)

1. Arvioi seuraavat väittämät rastittamalla yksi vastausvaihtoehdoista.	**Täysin samaa mieltä**	**Osittain samaa mieltä**	**En osaa sanoa**	**Osittain eri mieltä**	**Täysin eri mieltä**
GKOS-menetelmän opettelu oli kiinnostavaa.					
GKOS-menetelmän opettelu oli vaikeaa.					
GKOS-menetelmän opettelu oli palkitsevaa.					
GKOS-näppäinyhdistelmät tuntuivat loogisilta.					
GKOS testilaitteen ja –ohjelmiston käyttö oli helppoa.					
GKOS:lla kirjoittaminen tuotti vähemmän virheitä kuin nykyisin käyttämäni matkapuhelimen tekstinsyöttömenetelmä.					
GKOS:lla tekemäni kirjoitusvirheet johtuivat enimmäkseen muististani.					
GKOS:lla tekemäni kirjoitusvirheet johtuivat enimmäkseen huolimattomuudestani (ts. väärän näppäinyhdistelmän painaminen)					
Vireystilallani tuntui olevan vaikutusta kirjoitusnopeuteen.					
Harjoittelun lopussa GKOS-menetelmällä kirjoittaminen oli vaivatonta.					
GKOS-kirjainkarttaa oli helppo tulkita.					
Olisin kiinnostunut korvaamaan nykyisen matkapuhelinsyöttömenetelmäni GKOS:lla, mikäli tekstinsyöttö on toteutettu ergonomisesti, eikä menetelmällä ole vaikutusta puhelimen fyysiseen kokoon tai hintaan.					
Olisin kiinnostunut käyttämään GKOS-tekstinsyöttömenetelmää matkapuhelimella, jos se olisi toteutettu Kuva 1:n esittämällä tavalla (painikkeet näytön takana, etupuolella kosketusnäyttö).					

Kuva 1: GKOS-konseptilaite


2. Arvioi oma matkapuhelinten tekstinsyöttömenetelmien nopeusjärjestys (1=nopein, 5=hitain).

Multi-tap [ ]
Ennustava tekstinsyöttö [ ]
QWERTY-keypad [ ]
Virtual-keyboard [ ]
GKOS (testin lopussa) [ ]

3. Laita kokeilemiesi matkapuhelinten tekstinsyöttömenetelmät mielekkyysjärjestykseen (1=mielekkäin, 5=vähiten mielekäs).

Multi-tap [ ]
Ennustava tekstinsyöttö [ ]
QWERTY-keypad [ ]
Virtual-keyboard [ ]
GKOS (testin lopussa) [ ]

4. GKOS-testissä kirjoitettiin viiden lauseen sarjoja neljän (tai kahdeksan) päivän aikana. Arvioi, kuinka monen harjoittelupäivän jälkeen et enää juurikaan tarvinnut GKOS-kirjainkarttaa (ts. et joutunut tarkistamaan tarvittavaa näppäinyhdistelmää kartasta paitsi joidenkin harvinaisempien merkkien kohdalla).

1. päivän jälkeen [ ] 3. päivän jälkeen [ ] Tarvitsisin kirjainkarttaa 4. päivän jälkeen [ ]
2. päivän jälkeen [ ] 4. päivän jälkeen [ ]

5. Oliko joidenkin tiettyjen kirjainten näppäinyhdistelmät vaikeampia muistaa GKOS-menetelmässä?

Kyllä [ ], mitkä:______________________________
Ei [ ]
En osaa sanoa [ ]

6. Oliko joidenkin tiettyjen kirjainten näppäinyhdistelmät vaikeampia painaa GKOS-menetelmässä?

Kyllä [ ], mitkä:______________________________
Ei [ ]
En osaa sanoa [ ]