The Effect of Feedback on Chord Typing

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***Abstract*—The amount of visual feedback when using a mobile device in a busy context is often limited. For example, while texting and walking in a crowded place, we need to focus on the environment and not on the phone. A way to type fast, accurately and with limited visual feedback is represented by chording keyboards. We present a study on such a chording keyboard prototype and analyze the influence of having visual, audio or no feedback at all on the typing process. The typing rates are the same under all three conditions, with an average of 20 words per minute, after approximately 350 minutes of practice. The average error rates are the lowest in the absence of feedback (2.41%) and the highest when the users can see what has been typed (4.03%). Considering these results, the proposed text input method is a viable option in situations where visual attention is already committed to other tasks.**

Keywords-chording keyboard; text entry; blind typing; feedback

I. Introduction

As mobile computing devices become increasingly popular, people want to be able to access them at all times. However, in a mobile environment, the amount of visual attention that can be devoted to a smartphone is often limited. This happens because the vision is already focused on the environment, and cannot be committed at the same time to the device or to the display. Many people initiate phone-calls while walking, but other functions such as text messaging or e-mail writing are less accessible. Even so, more than 40% of people write text messages while walking in public places [1]. This is potentially dangerous, as the visual attention is committed to typing and not to the surrounding environment. Therefore, to increase security and reduce the risk of accidents, it is important to find a method for entering text with limited visual feedback and without the need to look at the keys.

Using a chording keyboard [2] for text input will reduce the visual constraints. These keyboards enable users to generate a character by simultaneously pressing a combination of keys, similarly to playing a note on a musical instrument. With five keys, there are 31 combinations in which at least one key is pressed, enough for the 26 letters of the English alphabet plus five other characters. If the keys are placed in a position that is naturally under the fingertips, one can type with only one hand and without looking at them. The vision (or auditive feedback) is still needed occasionally to verify the output and to correct errors, but this requires considerably less commitment than continuously looking at the input device.

The likely reason chording devices are not very popular is that users require some training before being able to type, to learn the correspondence between key combinations and characters. A previous study [3] shows that people can learn to type with a five-key chording keyboard in less than 45 minutes if the key-to-character mapping is conveniently chosen.

We will analyze how different types of feedback affect the ability to type with a chording keyboard. To obtain the experimental data, users were asked to type under three different conditions: (1) with visual feedback, when they can see what has been typed; (2) with audio feedback, when they cannot see, but they hear the character that has been typed; (3) with neither visual nor audio feedback. We analyze the typing rates, the accuracy and the distribution of errors. We also evaluate the effect of the input device form factor on the typing process.

The paper is organized as follows. In Section II, we overview existing typing studies that evaluate different types of feedback. In Section III, we describe the experimental setup used in the study and in Section IV, we present the results. In Section V, we conclude the paper and discuss future directions.

II. Related Work

The condition when users type without looking at the text-input device and/or the display mostly occurs in mobile environments and is usually denoted as “blind” or “eyes-free” typing [4]. This explains why most blind-typing studies are performed using mobile keyboards such as 4×3 multi-tap keypads, mini-QWERTY, touchscreen keyboards, Twiddler [5], or other chording keyboards.

Silfverberg examined the effect of both tactile and visual feedback when using mobile phone keypads [4] and found that reduced tactile feedback increases the typing error rate. In addition, low visual feedback also leads to more errors, decreasing accuracy. A similar study made by Clawson et al. [6], concerning typing with mini-QWERTY keyboards, demonstrates the importance of seeing the keys while typing, but does not show any significant differences in typing

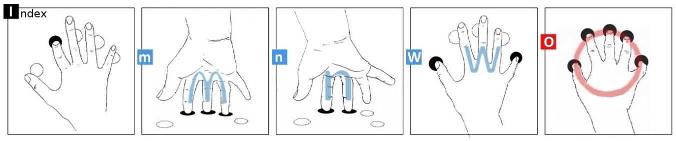

Figure 1. Examples of letter mappings for "**i**", "**m**", "**n**", "**w**" and "**o**".

speeds and error rates when users can or cannot see the typed text.

The above studies stress the importance of seeing the input device in the case of 4×3 multi-tap keypads and mini-QWERTY keyboards. However, this should not be an issue for most chording keyboards, which are specifically designed to be operated without looking at the keys. Typing experiments with limited visual feedback for the Twiddler chording keyboard were performed by Lyons et al. [7], and show that, surprisingly, typing and error rates actually improve with reduced visual feedback. Mascetti et al. propose and evaluate a Braille typing system for smartphones [8]. As it is intended for visually impaired persons, there is no visual, but only audio feedback.

Other studies, where participants do not look at the typing device or are involved in dynamic activities that require vision commitment, include the chording glove [9], a two-handed chorded software keyboard for PDA's [10], half-QWERTY touch typing [11], or the keyboard proposed by Gopher and Raij [12].

The chording keyboard used in this study has five keys, placed directly under the natural position of the fingertips. As users do not have to move their fingers from one key to another, it should make no difference if they are able to see the keys or not.

In a previous study [3], we proposed and evaluated a key-to-character mapping for a five-key chording keyboard. It is designed to minimize the learning time by assigning intuitive mnemonics to each character. Five examples of mnemonics are shown in Figure 1: "**i**" is given by the initial of the finger pressing the key (index); "**m**" and"**n**" are given by the shape of the fingers pressing the keys; "**w**" is given by the shape of the fingers not pressing the keys; for "**o**", we imagine five dots spread around a circle, and we obtain it by pressing all the keys. The complete mapping is given in the Appendix. The first part of the study evaluated the learnability of the mapping. We found that it can be completely learned in less than 45 minutes.

In the second part of the study, we analyzed the achievable text-entry rates and accuracy. We also assessed the difficulty of different key combinations by measuring the associated composition times. After 250 minutes of typing, the mean typing rate was 15.2 words per minute (wpm), with a maximum of 19.2 wpm. As a reference, after the same training time, the typing rates for multi-tap mobile phones are 12.4 wpm [13], for Twiddler 20.6 wpm [5], and for half-QWERTY approximately 24 wpm [4]. Rates of 20.3 wpm were reached by expert T9 users [14]. Note that the experimental conditions were not the same for all devices, and the given values are only indicative. The mean error rate during the experiment, accounting for both corrected and uncorrected errors, was 7.42%.

The chording keyboard was simulated on a regular desktop QWERTY keyboard. It only allowed for the use of five keys, each representing a key of the chording keyboard.

III. Experimental Setup

The input method that we present is designed to be used in situations where the visual attention is partially or totally unavailable for the typing process. In these conditions, audio feedback is often suggested as an alternative. This is indeed useful in some environments, but could be difficult to use in noisy areas. Considering this, we designed a 3×10 within-subjects experiment, where we analyzed three different typing conditions. Under the first condition, subjects are able to see the outcome of what they have typed, under the second condition they receive voice output for each typed letter (without visual feedback), and under the third condition they receive no feedback at all about the typing. From here on, we will refer to these conditions as visual, auditive, and no-feedback, respectively.

We asked ten PhD students from our university (eight male and two female, between 24 and 31 years old) to type using a chording keyboard. All of them had participated in the learnability part of the previous study, so they already knew the mapping and had had 45 minutes of training. They used a five-key chording keyboard prototype with the keys placed around a computer mouse, presented in Figure 2. We chose this design for the prototype because we wanted the subjects to see a practical application of a chording device that allows for typing and screen navigation at the same time. The keyboard is designed using an Arduino Pro Mini microcontroller board and communicates with the computer by Bluetooth. The buttons are placed in a position that is naturally under the fingertips when a user holds the palm on the mouse.

The participants were asked to type for 10 sessions of 30 minutes. Each session consisted of three rounds of 10 minutes separated by breaks of 2 minutes, and each round corresponded to a different typing condition. The order of the typing conditions was random for each session, but the same for all subjects. For each user, the typing sessions took place on consecutive days, with the exception of weekends.

The first session enabled the subjects to remember the mapping between keys and characters, and a help image showing the key combination for the letter to be typed was displayed. Starting with the second session, this image was no longer displayed. In the beginning of each round, the participants warmed up by typing each letter of the alphabet.

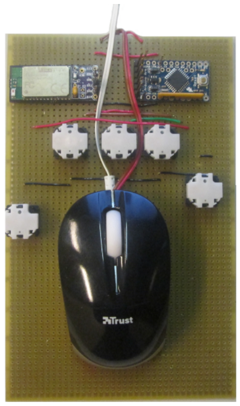

Figure 2. Chording keyboard prototype

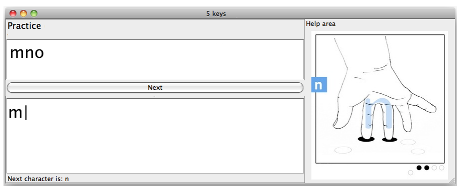

Figure 3. Typing application screenshot for the visual feedback condition

Afterwards, they typed phrases from a set considered representative of the English language [15]. These phrases were pre-prepared before the experiment to contain only small letters and no punctuation signs.

A Java application was designed to display the text to be typed, to monitor the pressed keys and, in case of errors, to check what character was typed in lieu of the correct one. A screenshot of the application for the visual feedback condition is shown in Figure 3. The top-left window contains the text to be typed, and the bottom-left window represents the typing area. The help image is displayed on the right.

The subjects were instructed to type as quickly and accurately as possible. They were told to not correct eventual mistakes and keep typing, but this was not enforced and they could delete typed text. As a reward for the time commitment during the experiment, they received a fixed monetary compensation for the first nine sessions. For additional motivation, for the last session, the reward was proportional to the number of typed words and to the accuracy.

The total amount of data gathered during the experiment consists of $40\,345$ words, out of which 4052 (10.17%) contain errors. The total number of characters is $219\,308$, from which 5889 (2.69%) are errors.

IV. Results

The main purpose of the experiment is to analyze how different typing conditions affect a person's typing rate and accuracy. Even if the mapping is the same, the input devices are different between this study and our previous work. This enables us to also verify the influence of the form factor of the device on the text entry process.

A. Typing Speed

We use the words-per-minute measure to describe the text entry speed. This is defined as

$$wpm = \frac{60L}{t}\frac{1}{5} \qquad (1)$$

where L is the total number of typed characters and t is the typing time in seconds. The scaling factor of 1/5 is based on the fact that the average English word length is approximately 5 characters. Because the average word length for the typed text differs from one session to another, the use of the above formula provides a more reliable estimate than actually counting the words.

In Figure 4, we show the average typing rates for each session and for each condition. For the first three sessions, the rates are higher for the no-feedback condition, and the analysis of variance tests showed that the differences are statistically significant ($F = 10.85$, $p < 0.001$). From the fourth session onward, there are no more visible differences between the typing rates. Moreover, the effect of the feedback type is no longer significant ($F = 0.28$, $p = 0.75$). This probably happens because in the beginning subjects pause typing to check the provided feedback, visual or audio. As they gain experience, they become more confident and do not analyze the feedback so often, therefore reducing the differences between conditions.

In Figure 5, we show the typing rates for each user and for each session, during the no-feedback condition. As it can be noticed, the fastest subject can type three times faster than the slowest subject, the differences being statistically significant ($F = 53.8$, $p < 0.001$).

The average typing rates at the end of the experiment are 19.77, 20.16 and 20.00 wpm for the visual, audio and no-feedback conditions, with maximums of 31.24, 30.48 and 31.78 wpm, respectively. Considering the participants' experience from the previous experiment, these values correspond to approximately 350 minutes of practice. Because the text entry rates will probably still improve, we use

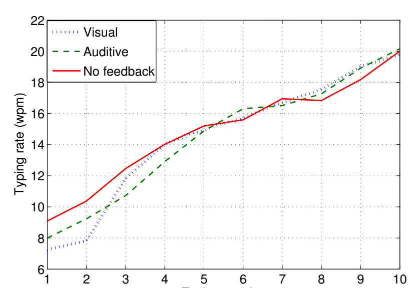

Figure 4. Average typing rates for each condition and for each typing session

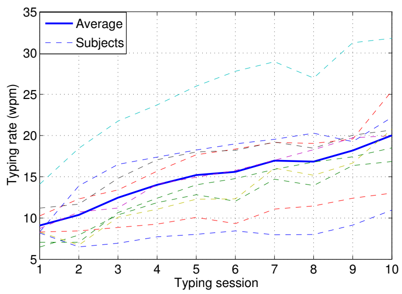

Figure 5. Average typing rates for each subject and for each typing session, for the no-feedback condition

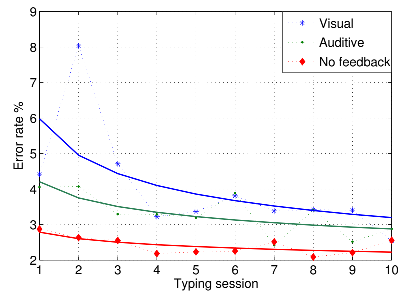

Figure 6. Average error rates for each condition and for each typing session

exponential regressions to estimate how fast people will be able to type after longer training periods. Based on these calculations, after 20 sessions (300 more minutes of practice), the average could be 26 wpm, and the fastest typist could reach 42 wpm.

B. Error Rates

The error rates are computed as the number of errors divided by the number of typed characters. Errors include substitutions (when one character is typed for another), insertions (when an extra character is typed) and deletions (when a character is missing). Each substitution, insertion and deletion counts as one error.

In Figure 6, we display the average error rates for each session, accounting for both uncorrected and corrected errors, and the corresponding exponential regressions. All of the error rates are below 5%, except one. The averages for all sessions and for all users under the visual/auditive/no-feedback conditions are 4.03%, 3.30% and 2.41%, respectively. Analysis of variance tests show that feedback plays a relevant role in the error rates ($F = 25.57$, $p < 0.001$).

Initially, it might seem surprising that the error rates are the lowest for the no-feedback condition and the highest for the visual condition. However, this is explained by the fact that increased cognitive loads generally lead to more errors [16]. For our study, the cognitive load is the highest in the visual condition: users can check the whole typed phrase; it is reduced by the audio condition when users only hear the last typed character, and minimum in the absence of feedback. Noticing an error could cause someone to become less focused, thus favoring new mistakes.

In Figure 6, we notice the high error rate for the second typing session, visual condition. The reason for this could be the fact that in the first session the help image was always displayed, whereas in the second session it was hidden. Moreover, the first typing condition in session 2 was the visual one, giving subjects more practice time for the audio and no-feedback conditions, which do not have much of an increase in the error rates.

The error rates decrease during the first four sessions (with the exception mentioned in the previous paragraph), but afterwards they remain stationary or even increase. Similar effects, when after a certain point the error rates do not decrease anymore as users gain experience, were also noticed by Matias et al. [11] and Lyons et al. [5].

Error Patterns: In Figure 7, we present the error rates for each character and for each typing condition. We notice that the character errors respect the pattern of the overall error rates: the highest for the visual condition and the lowest for the no-feedback condition, this being the case for 20 of the 27 analyzed characters.

For all three conditions, the error rates are higher for characters that are less frequent in the English language, such as “**q**” and “**j**”. The character error rates are similar between the three conditions, up to a scaling factor: if a character has an error rate lower than other characters for a specific condition, it usually also has a lower error rate relative to the same other characters for the other conditions. This is confirmed by the correlation coefficients between the error vectors, all above 0.9.

To analyze in more detail the error patterns, we determine the confusion matrices for each typing condition. They are square matrices with rows and columns labeled with all possible characters. The value at position ij shows the frequency of character j being typed when i was intended. The values are given as percentages of the total number of occurrences for character i. The three matrices are similar, with correlation coefficients higher than 0.99. If we consider only the erroneously typed characters (by setting the diagonal values to zero), the correlation coefficients are above 0.9, still showing a strong similarity: if one character is frequently typed instead of another under one condition, the same will happen under the other two conditions; if the probability for one character to be typed instead of another is low under one condition, it is also low under the other two conditions.

C. Typing-Device Form Factor

When designing a keyboard, an important aspect is the form factor: where the keys are placed, how hard they have to be pressed, and what the provided tactile feedback is.

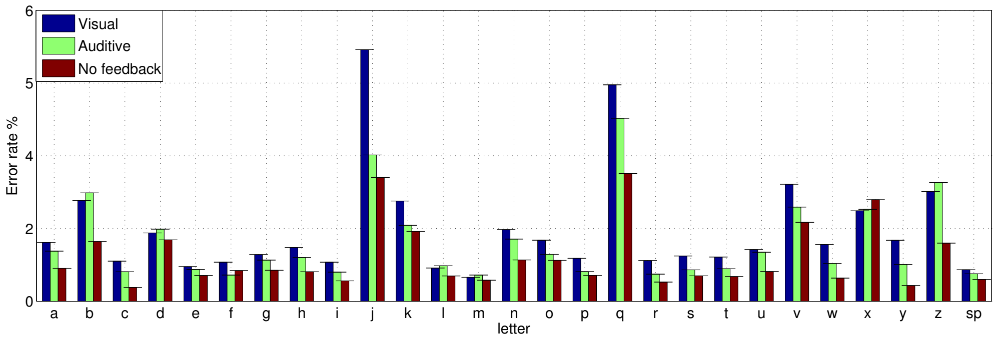

Figure 7. Error rates for each character for each typing condition

Modifying these characteristics will most likely influence the typing process, because a keyboard can be perceived based on them as difficult or comfortable to use. In the absence of visual/auditive feedback, tactile feedback is important because it could be the only way to let the user know that a character has been typed. This is why we used buttons that provide a strong passive feedback, and not touch or pressure sensors.

We evaluate the influence of the typing device form factor on the typing process by comparing the typing rates and the error rates under the visual condition with those from our previous work. Even if the experiments took place at different times, this is motivated by the fact that the main difference is the input device, whereas the other experimental conditions are similar. This time, the subjects used a real prototype, not a chording keyboard simulated on a regular QWERTY desktop keyboard; the keys are not the same and also placed in a different position. For both studies, the participants had the same education level (all master's or PhD students at our university), the gender distribution was similar (two females out of ten vs. one female out of six), the typed phrases were from the same set, the Java application used to see the text to be typed was the same, and the participants received similar financial compensations.

As can be observed in Table I, after the same amounts of training time, the typing rates are higher than those in the previous work (15.73 wpm, compared to 12.16 wpm). The time values start from 1.5 hours and not from 30 minutes (the duration of one session), thus including the previous typing experience of the subjects. The differences in the typing speed are statistically significant ($F = 12.16$, $p < 0.001$), thus confirming the importance of the input-device form factor.

TABLE I. AVERAGE TYPING RATES FOR THE VISUAL CONDITION AND FOR THE PREVIOUS EXPERIMENT

Training time (hours)	1.5	2	2.5	3	3.5	4
Visual condition (wpm)	7.23	7.82	11.83	14.01	14.97	15.73
Previous study (wpm)	6.79	7.83	8.87	9.40	10.37	12.16

The average error rate at the end of the previous study was 6.43%. After the same typing time, the average error rate for the visual condition was 3.91%. The difference could also be explained by different input devices and is statistically significant ($F = 55.2$, $p < 0.001$). Even if the average error rates are not the same, the error patterns are similar for the two studies, therefore we can conclude that they depend on the mapping more than on the typing condition or on the form factor.

V. Conclusion and Future Work

In this paper, we have presented a study evaluating the effect of different types of feedback for a chording keyboard. The subjects were asked to type under three conditions: with visual feedback, with auditive feedback and with no feedback at all. Because of the keyboard design, whether the user can see the keys or not should not make any difference on the typing process — at the end of the experiment, participants confirmed that they did not look at the keys. Similarly, someone playing a saxophone does not look at the keys to be pressed.

After approximately 350 minutes of typing (taking into consideration the previous typing experience of the subjects), the average entry rates are approximately 20 wpm under all three conditions, with the maximums above 30 wpm. We conclude, therefore, that having visual, audio or no feedback has no influence on the typing speed.

The average error rates are 2.41% under the no-feedback, 3.30% under the auditive and 4.03% under the visual conditions. This is explained by the fact that the cognitive loads are different under the three typing conditions: the highest under the visual and the lowest under the no-feedback condition. Hence, not seeing the typed text actually represents an advantage. The error patterns are similar between conditions, the characters with the highest error rates and the most common substitutions being the same.

This study shows that the lack of visual or audio feedback does not impede the typing process, therefore the chording keyboard can be used reliably in situations where a person is not able to continuously check the output. Besides this, the keyboard can be used with only one hand. The small number of keys also represents an advantage from the size and design flexibility point of view. As the study took place in an office, to go one step further, we should set up the experiment in a dynamic environment (for example, have the participants walking or jogging).

In addition to the effect of different typing conditions, the experiment enables us to evaluate the importance of different form factors for the input device: using the keyboard prototype and not a simulated keyboard as in our previous work leads to higher typing rates and lower error rates. However, no attempt was made to optimize the form factor, and other designs might further improve these measures.

So far, we have envisaged the chording keyboard as a means of typing in dynamic or busy environments. Due to its advantages, it can also be successfully used in other areas: For example, it can facilitate text input for disabled users who can only use one hand, or for persons who are visually impaired.

APPENDIX

In Table II, we present the key combinations corresponding to the characters used in our study.

TABLE II. FIVE-BIT CODES FOR THE USED CHARACTERS

Character	5-bit code	Character	5-bit code
a	00110	q	01101
b	10111	r	00010
c	10100	s	10101
d	11101	t	10000
e	11000	u	01001
f	01010	v	10011
g	11100	w	10001
h	11001	x	11011
i	01000	y	10110
j	01011	z	10010
k	11010	*space*	11110
l	00111	*backspace*	01111
m	01110	*enter*	00011
n	01100	*period*	00100
o	11111	*comma*	00101
p	00001		

Each key combination can be represented by a five-bit codeword in which the first digit represents the key under the thumb, the second digit the key under the index, etc. The value of a position is 1 if the corresponding key is pressed. So, for instance, 10111 (the codeword for "**b**") means that all fingers except the index press the keys.

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