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The Effects of Word Completion and Word Prediction on Typing Rates Using On-Screen Keyboards

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Word prediction is often recommended by therapists as a means to improve typing speed for clients with physical limitations. Although literature suggests that word prediction does have an effect on writing proficiency, increased speed is not one of its benefits when used with a standard keyboard. One reason given for the failure of word prediction to accelerate typing is that the user must look away from any source document to scan the prediction list during typing. Looking away from the source document may slow the typist more than any acceleration offered by word prediction. For input methods that already require the typist to look away from the copy, this effect might be irrelevant. The focus of this research was to determine whether word completion or word prediction programs would increase typing speed when used with an input method (an on-screen keyboard) that also requires looking away from the source document. Ten people, five men and five women, aged 20 to 38 years, participated in this study. The study used a single-subject, successive intervention design to test typing speed and accuracy using an on-screen keyboard with integrated word prediction software. Seven participants had their fastest typing speed with word prediction. Two participants had their fastest typing speed with word completion. Only one participant demonstrated no improvement in speed when using these two programs. Overall, these results show that the use of word prediction and word completion may assist on-screen keyboard users to improve typing speed.

Key Words: On-screen keyboard—Word prediction—Word completion—Typing speed—Assistive technology.

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LITERATURE REVIEW

Occupational therapists may use meaningful activities as modalities to restore function and teach compensatory strategies or may help clients achieve access to meaningful activities as a goal in itself. They may use an occupation as a therapeutic tool to achieve a secondary goal. "Occupation includes the day-to-day activities that enable people to sustain themselves, to contribute to the life of their family, and to participate in the broader society" (Crepeau, Cohn, & Boyt Schell, 2003, p. 28). Furthermore, occupational therapy requires its practitioners to use enabling and meaningful activities to promote health. As stated by Crepeau et al. (2003), "The overarching goal of occupational therapy is to improve the health and quality of life of people through engagement in meaningful and important occupations" (p. 28).

In today's society, computers have revolutionized the way people access information, perform work and school assignments, and correspond with others. The computer has evolved from being a novelty to being a tool that is necessary to access the world around us (Anson, 1997). Because the computer has become such a necessity to functioning in today's world, occupational therapists must consider the use of this tool as a meaningful activity for obtaining information, performing work and school tasks, and communicating with others. So pervasive has information seeking become that the search engine Google has entered the vocabulary as a verb (e.g., "Have you Googled yourself?") and is a primary means of gathering information on any subject for a large segment of the population. For a person with a disability, communication via the computer includes the typical application of communicating with individuals who are at a distance (i.e., through e-mail) but may also include communicating with individuals in the immediate environment (i.e., augmentative communication). Furthermore, students at various levels in their education require the use of computers as a means to enhance their learning.

Brandon Hall estimates the e-learning sector will grow from $10.3 billion in 2002 to $83.1 billion in 2006, and eventually swelling to over $212 billion by 2011. The trend is evidenced by an 80% growth by the University of Phoenix Online, whose virtual campuses boasted 72,230 students as of May 2003 (Greenspan, 2003).

Last, in today's competitive job market, computer familiarity and use is a skill that is highly encouraged by employers because their employees are required to rely more on technology to perform optimally. "Most U.S. workers feel at ease with technology, according to a new Society of Financial Service Professionals survey of 1,130 members. . . . Using technology increases knowledge in the workplace, said 87% of participants, while 80% said technology develops job skills" (Kelsey, 2001).

An able-bodied person commonly accesses the computer through the keyboard and mouse. When a person acquires a disability (or is born with a disability), the keyboard and mouse may cease to be tools that promote access and instead become barriers to participation in computer-based activities. The use of the keyboard and mouse may be limited by restrictions in range of motion, decreased fine-motor skills, or inability to coordinate movements across multiple joints.

Finding alternative means for people with physical disabilities to access a computer system is imperative in assisting them to obtain information, perform work and school tasks, and communicate with others. A broad range of computer access technologies are currently on the market (Anson, 1997). Computer access technologies include input technologies, output technologies, and enhancement technologies. Input technologies are devices or programs that enhance the ability of the user to enter information into the computer. These include items such as expanded keyboards, mouse emulators, or on-screen keyboards. Output technologies allow the user to obtain information from the computer other than through the conventional display. Output technologies include devices such as alternative sound systems, screen enlargers, and refreshable Braille. Finally, enhancement technologies are intended to compensate, at least in part, for the lower performance of a person with physical or sensory limitations and to improve productivity. Enhancement technologies include strategies such as macros, abbreviation expansion, and word prediction.

For individuals who have difficulty using a standard keyboard effectively but who can use a standard mouse or mouse emulator with good facility, an on-screen keyboard is an access method that is easily learned, draws on prior experience to generate text on a computer, and allows reasonable levels of productivity. An on-screen keyboard is an image of a keyboard that is located on the screen of the computer. To type using an on-screen keyboard, the user positions the mouse pointer over the desired letter, and performs an action (generating a mouse click, performing a gesture, or simply waiting for a prescribed period of time), and the character is sent to the computer application being used. Although an on-screen keyboard makes typing possible for the individual who can only move the mouse pointer, it does not allow a person to type at the same rate as an able-bodied person using the standard keyboard. Whereas the standard keyboard allows typing with all 10 fingers, an on-screen keyboard allows only a single "digit" (the mouse pointer) to be used. As a result, an able-bodied person types significantly slower on an on-screen keyboard than with the standard keyboard. Because an individual with a disability may have decreased ability to move the mouse pointer, he or she may type even slower. To minimize the effect of single-digit typing and decreased motor control, some means of accelerating typing is needed to improve the productivity of this input method.

One approach that may potentially improve typing speed for users of on-screen keyboards is to incorporate word completion or word prediction. Word completion and word prediction were originally developed for individuals with physical disabilities to decrease the number of keystrokes required to type words and sentences (MacArthur, 1996). Word completion provides the user with one or more predictive suggestions after the user has typed the initial letters of a word (Hunnicutt & Carlberger, 2001). Word prediction is a feature of some word completion programs that, after a selection has been made for the current word, attempts to predict the next word in the sentence.

Prior research indicates that using a word completion or word prediction program has some advantages for the user. Individuals who have low endurance could benefit from the reduction in keystrokes that word prediction and word completion can provide. Word prediction has been noted to reduce the number of keystrokes by up to half

(Klund & Novak, 1997; Langer & Hickey, 1999; Raskind & Higgins, 1998). This reduction of keystrokes while using word prediction could allow the typist with limited endurance to accomplish more work with the limited energy available for task completion. People with poor keyboarding skills find typing with word prediction easier than keyboarding alone because a single difficult keystroke can replace many of equal difficulty (Raskind & Higgins, 1998).

In addition to keystroke savings, researchers have noted several other potential advantages to using word prediction. Word prediction programs can act as a compensatory spelling aid (Raskind & Higgins, 1998), cueing the typist that the initial letters of a word may be incorrect because the balance of the word has not appeared on the prediction list. Word prediction has also been shown to increase user attention span, improve self-esteem, increase ability to write independently, and improve language and vocabulary development (Klund & Novak, 1997). Although research indicates that keystroke reduction and other benefits occur when using word prediction, none of these studies suggest that this keystroke reduction increased typing speed when using a standard keyboard.

Although word prediction has been shown to have advantages for some users, it can also make the composition process more complex, which may slow the typist. First, the word list may distract the user, as the ever-changing presentation draws the attention away from the sentence being constructed. The cognitive process of selecting words from a prediction list may disrupt the creative process and interfere with the flow of composition, especially for people who have significant difficulty in word recognition (Anson, 1993; Gibler & Childress, 1982; Raskind & Higgins, 1998). Word prediction can provide too much of a good thing. Hunnicutt and Carlberger (2001) stated that "as the number of predictions grow, the increase in keystroke savings diminish (i.e. the keystroke savings plateau)" (p. 263). As more predictions are listed, the user must inspect a longer word list, and the chance of missing the desired word on the list increases. Some users may look only at the predictions at the top of the list and ignore the words lower on the list.

According to Soede and Foulds (1986), word prediction is successful in reducing the motor load typing at the expense of increasing the cognitive and perceptual load on the user. Horstmann and Levine (1991) stated, "Use of a word prediction feature requires additional cognitive and perceptual processes, and these are the major contributors to the increase in selection time" (p. 100). A visual search of the prediction list and the user's decision about whether the word is on the list are two of the processes researchers attributed to increased selection time (Anson, 1993; Gibler & Childress, 1982). Cognitive and perceptual loads imposed on the user are associated with a time cost that can offset and even overwhelm the keystroke savings provided by word prediction (Koester & Levine, 1996). This is evidenced by the finding that the addition of word prediction in typing did not improve typing speed and may decrease it. Koester and Levine (1996) found that, for experienced mouth-stick typists, the addition of word prediction reduced typing speeds from about 20 words per minute (WPM) to about 12 WPM. Among children with spina bifida and hydrocephalus, Tam, Reid, Naumann, and O'Keefe (2002) found no significant change in typing speed with the addition of word prediction but did find that three of four participants typed faster when the word prediction was on the lower edge of the screen.

Another component of the cognitive and perceptual load may be the continual shifting of the point of regard between the material being typed and the word prediction list and the input site. According to Tam et al. (2002), individuals with lower intelligence scores and low scores in memory and reading may have trouble keeping track of their place on the copy material. Three of the four participants typed faster when the word prediction list was on the lower edge of the screen, so that the list location was nearer the keyboard. Anson (1993) found that the participants who reported no impairment in intelligence and memory also had difficulty keeping track of their place on the source document. The participants in the Anson study reported that because they had to look up from the source copy to scan the word prediction list, they often lost their place. The time saved because of keystroke reductions was outweighed by the loss of time to search for their place. In fact, for 7 of 10 participants in this study, word prediction reduced the typing speed in direct proportion to the number of times it was used (Anson, 1993).

It appears that the cognitive load of word prediction may have several components. Among these are the need to alternate cognitive processing between message construction (the selection and arranging of the words to convey the intended meaning) and component selection (scanning the word list presented by a word prediction program) and the need to alternate point of regard between the writing area and the word list. The compositional component of word prediction may not be amenable to change. In fact, it is possible that the primary candidates for word prediction are individuals for whom the primary limit to writing is physical: those who can compose mentally faster than they can produce words on the screen.

If the shifting of point of regard from the source to word prediction list to keyboard is a significant component of the cognitive load of word prediction, minimizing the shifts might reduce the cognitive load. One approach to doing this is to place the prediction list at the point of regard. Co:Writer does this by accepting generated text into the program and transmitting completed messages to the target program. Another word prediction package, WordQ, moves the prediction window to the system cursor, so that the shift of regard is minimized. Both of these approaches add cognitive complexity to the task, making it difficult to assess the effect of shifting point of regard on cognitive overhead. In Co:Writer, messages are composed out of visual context, a sentence at a time, then transmitted to the target program. The user must remember the context of the message. With WordQ, the prediction window sometimes covers the information the user is trying to view, such as menu entries or screen controls. Both of these changes to the writing process confound the effect of shifting focus. To assess the effect of shifting the point of regard on word prediction, a method should be found that minimizes other changes.

A person using an on-screen keyboard must look away from the source document to generate text. The addition of word prediction to an on-screen keyboard minimally changes the complexity of the cognitive task, so that the decrease in keystrokes afforded by word prediction may be assessed in isolation of other changes in processing. Preliminary data collected by Anson (1993) suggested that, for typists using on-screen keyboards, word completion might produce a performance gain.

The focus of this research is to determine whether word completion or word prediction programs will increase typing speed when used with an input method (on-screen keyboard) that also requires looking away from the source document. We hypothesize that the addition of word completion to an on-screen keyboard will enhance typing performance as compared with the use of an on-screen keyboard without word completion. Because word prediction requires even fewer keystrokes, we hypothesize that the addition of this feature will improve typing speeds over both the on-screen keyboard alone and the on-screen keyboard with word completion.

METHOD

Research Design

This study used a single-subject, successive intervention design to test typing speed and accuracy using an on-screen keyboard with integrated word prediction software. The goal of this study was to determine whether word completion and word prediction help or hinder the typing process when used in conjunction with the on-screen keyboard. To make this analysis, the participants were tested using each of the following options: on-screen keyboard only, on-screen keyboard with word completion, and on-screen keyboard with word prediction.

Participants

Ten able-bodied people, five men and five women, participated in this study. The participants' ages ranged from 20 to 38 years. Each participant had vision adequate to read a document printed in 12-point Times New Roman font, was able to read and speak English fluently, and was able to sit unsupported for more than 30 min at a time in an armless chair.

Instrumentation

Equipment / Measurement Tools

Each participant used a single computer for all typing trials. All text was entered into one of five Windows-based, standard laptop computers, with Windows XP operating systems and Pentium or higher processors operating at a minimum of 500 MHz. Each of the computers used in this study had at least 128 MB of RAM. All text was typed into Microsoft Word. During text entry, the laptop computers were set up with the keyboard covered to remove the temptation to use the physical keyboard for incidental action or data entry.

All text entry was performed using ScreenDoors 2000 (Madentec, Edmonton, Alberta, Canada) and a Microsoft-compatible mouse. ScreenDoors 2000 has a number of options for keyboard layouts. To standardize the size of the keyboard, the researchers created a paper template with a "window" 7 in. (ca. 17.8 cm) wide and 2.5 in. (6.35 cm) high. The on-screen keyboard was sized to just fill this window prior to each trial. The word prediction tool bar was positioned horizontally at the top of the onscreen keyboard. (The word prediction window was not included inside the template space.)

The on-screen keyboard was located on the bottom of the computer screen, and the blank Microsoft Word document was located at the top of the screen. The window for Microsoft Word was sized so that no portion of it was covered by the on-screen keyboard, but the document window as large as possible in the remaining area of the display.

Each researcher used a Radio Shack Rotary digital timer to time the 20-min typing interval for each trial. The printed text was placed on a vertical document holder, which the participant was allowed to place on his or her preferred side of the computer screen.

Source Document

Participants were asked to type test segments from *A Case of Identity,* by Sir Arthur Conan Doyle. The researchers separated the source document into approximately 500-word chunks prior to beginning data collection. (Each segment ended at the end of a paragraph that contained the 500th word.) The entire novel was imported into ScreenDoors' dictionary to familiarize the system with commonly used words and word patterns of the text. The documents were formatted to remove extraneous line breaks and to be in Times Roman font, double spaced. The participants were given segments of the novel in sequential order. The novel used had only 13 segments. If a participant required more than 13 segments to complete the research, the participant would return back to the first segment of text.

Operational Definitions

Accuracy

The Compare Documents feature of Microsoft Word was used to analyze the differences between a typing trial compared to the original source document.

Error Count

Errors could include deleted letters, letter reversals, deleted words, word reversals, or deletions of entire sentences. Although a given difference identified by the Compare Documents feature might have included one or more of these individual errors, each identified difference between the documents was counted as a single error. Although this may undercount individual differences, it did ensure that agreement of count could be obtained. In the course of data analysis, it was discovered that the AutoFormat feature of Microsoft Word had changed some characters (e.g., double quote into "open double quote") and that some of the differences were in the number of spaces at the end of a sentence. Because these differences were not under the control of the participants, they were not included in the error count.

$$\begin{aligned}&\text{Percent Accuracy}\\&\quad= [(\text{Total Number of Words Typed}\\&\qquad - \text{Number of Errors})\\&\qquad \div (\text{Total Words Typed})]100.\end{aligned}$$

Plateau

Although continued exposure to any assistive technology over long periods of time will generally result in improved performance, a research study must control exposure to allow timely results. For the purposes of this study, a participant was considered to have reached a proficiency plateau when the number of words typed for three consecutive trials had an intertrial difference of no more than 7%. Earlier studies have demonstrated that normal typing can show typing speed variations over 20 min of greater than 5% and that a 10% difference can be obtained while a participant continues to make substantial gains in performance. Although, in some cases, the difference between the first and last trials can differ by as much as 14% using this standard, experience has shown that the typical participant will show a definite leveling of performance at this point. The 7% standard seems to be achievable by typical participants but in general only when progress has slowed substantially.

WPM

WPM was calculated using the formula

$$\text{WPM} = \frac{\text{Words Typed in 20 min}}{\text{20 min}}.$$

Setup

The environment for each trial was arranged the same. The individual was positioned 18–36 in. (ca. 45.7–91.4 cm) from the monitor screen to provide a neutral focus distance. The laptop computer was placed on a table, and the participant was seated in an armless chair. A cover was positioned over the keyboard of the laptop. The mouse and mouse pad were positioned on the user's dominant side relative to the screen. The vertical document holder was placed on the participant's preferred side next to the monitor.

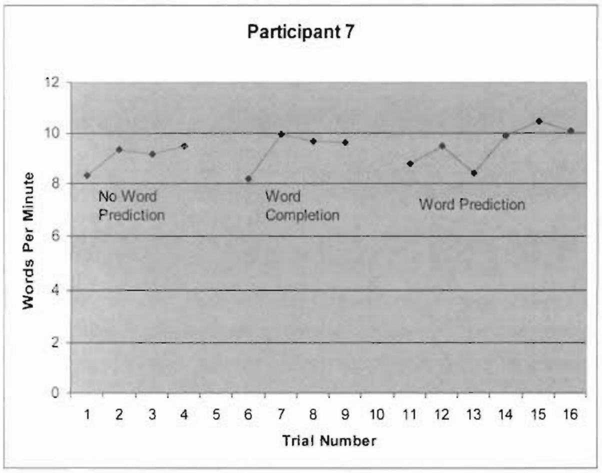

FIG. 1. Sample data showing advantages of word prediction and word completion over on-screen keyboard alone.

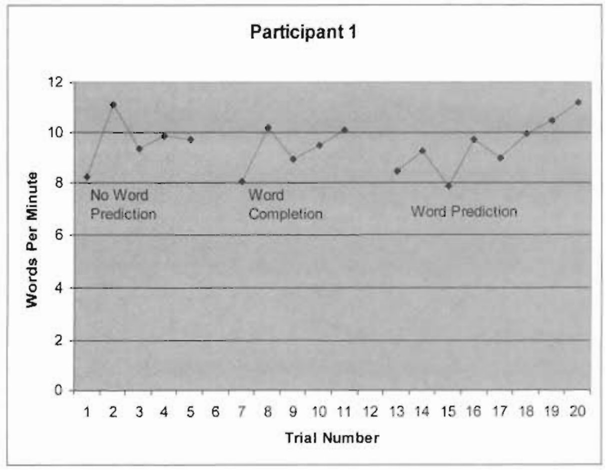

FIG. 2. Sample data showing advantages of word prediction.

Procedures

Prior to the start of research trials, training took take place to familiarize each person with the use of the on-screen keyboard and word completion and word prediction software. A standard explanation of each feature was read by the researchers to the participants. Participants were asked to try each feature by typing one sentence from the consent form after each explanation was provided. After this initial training, participants began the trials. The order of precedence of each modality (on-screen keyboard, on-screen keyboard with word completion, and on-screen keyboard with word prediction) was balanced across participants to control for possible order effects.

At each typing session, the participants were allowed to perform up to three 20-min typing trials, with no more than two sessions per day and a minimum of 1 hr for rest between sessions. This ensured that fatigue would not be an issue in typing speed or accuracy. The participants repeated trials using each method for data entry until their scores reached a plateau.

At each trial, the participants were provided with the preselected text for reproduction using the on-screen keyboard with the appropriate enhancements. The researcher set the digital timer for 20 min and gave the participant the following instructions, "When I say go, I'd like you to type this document as quickly and accurately as you can. Are you ready? Go!" The researcher started the timer. After 20 min, the researcher said, "Stop." Any partial word at the end of the document was discarded, and the document was saved.

Data Analysis

Speed and accuracy of the completed text were analyzed using the Word Count and Compare Documents tools of Microsoft Word. After each session, the participant's scores were plotted on a graph to determine whether a plateau in scores had been reached (see Figs. 1 and 2). For purposes of comparison across entry modalities, the scores of the three trials that establish plateau were averaged, and these averages were compared within each participant. (Because this is a single-participant study, comparisons across participants would not be valid.)

RESULTS

As shown in Table 1, 7 of the 10 participants had the highest typing speed for word prediction. Five of these seven people had the second highest typing speed using word completion and the lowest speed while typing using no word prediction (see Table 1). Two of the seven had the second highest typing speed using no word prediction and the slowest speed when using word completion (see Table 1).

Word completion was, as predicted, also faster than the on-screen keyboard alone in 7 of the 10 participants. Five of these participants had their highest speed with word prediction, followed by word completion and no word prediction. Two participants had their fastest speed with word completion, followed by word prediction.

The typing of the participants was also examined for differences in error rate. All methods were found to be highly accurate, and no systematic differences in error rate were identified between the methods. It does appear that, for those individuals

TABLE 1. Participant results for words per minute and percent error for all input methods

	Words per minute			Percent error		
Participant number	No word prediction	Word completion	Word prediction	No word prediction	Word completion	Word prediction
1	9.6	9.5	10.5	2.4	1.6	1.1
2	9.2	10.7	11.1	4.5	2.9	2.7
3	9.3	10.1	10.3	1.6	1.1	0.8
4	8.9	9.3	9.0	0.9	0.5	1.3
5	12.0	10.5	10.7	0.3	0.5	0.3
6	9.1	8.8	9.8	0.6	0.6	0.7
7	9.3	9.7	10.1	1.1	1.9	1.5
8	11.9	12.5	11.0	1.4	0.9	1.4
9	6.9	7.3	7.9	3.4	0.7	1.5
10	6.8	9.5	9.9	0.5	0.7	1.7

with high error rates without word prediction, the use of word prediction and word completion reduced typing errors. This effect could be explained by the fact that the typists were hitting fewer keys themselves when using this technology and so had less opportunity to make errors.

The results of our study show that 7 of the 10 participants had the fastest typing speed when using word prediction software. In addition, 7 of the 10 participants had faster speeds when using word completion than the on-screen keyboard alone. The seven people who typed the fastest using word prediction required five to eight trials to plateau at 7%. In contrast, the three people who typed the fastest on word completion or no word prediction required only three to six trials to plateau at 7% with word prediction. It is possible that, given more practice, these individuals would have learned to use word prediction more efficiently and shown additional improvement in typing speeds; however, our protocol did not allow for continued practice once the 7% proficiency standard was achieved.

Although the majority of the participants had the fastest speed using word prediction, most of these participants felt that using word prediction was the most frustrating of the three methods of access used in the research process. Nine of the 10 participants stated that they disliked looking away from the document to search the list because they lost their place on the copy. (Note that these were able-bodied typists, who may have been frustrated by using the on-screen keyboard and confused this with the word prediction process.) Eight of the 10 felt that searching through the word list was tedious and distracting. After all trials were completed, only three of the seven participants who had their fastest speed on word prediction felt that using word prediction was beneficial to increasing their typing speed.

DISCUSSION

Historically, word prediction and word completion programs have been shown not to improve typing speed when used with a standard keyboard. This has been attributed to increased cognitive load of using word prediction and to the user's looking away from the source copy to search the word prediction list. For individuals using an on-screen keyboard, looking away from the source copy is already required by the input method, and the addition of word prediction will not add this factor to the process of typing. This allows an assessment of the keystroke savings of word prediction independent of the shift of point of regard, so that the balance of keystroke savings versus cognitive load can be assessed.

In this study, most participants were able to type faster using word prediction as compared with both word completion and the on-screen keyboard alone. Similarly, most typists were able to type faster using word completion than with the on-screen keyboard alone. Thus, the use of word completion and word prediction to improve productivity for the users of on-screen keyboard users is supported by this study. However, the changes noted were relatively small. Although word prediction theoretically allows reductions in keystrokes of 30%–50%, the actual changes in productivity were generally less than 10%.

A second source of delay for users of word prediction is considered to be the cognitive load afforded by the need to scan the word list and make selections from it. When changing visual regard is controlled, as in this study, the effect of cognitive load can be more readily assessed. Most of those who were able to type fastest using word prediction also found it to be the most "frustrating" input method in this study. In past studies (Anson, 1993; Tam et al., 2002), participants identified the need to look away from copy as a significant component of their frustration, as did 9 of 10 participants in this study. Because all input methods in this study required looking away from the source copy, it is likely that the need to look at the prediction window was conflated with the need to scan the list and select words from it. This increased need to scan the word list, and its accompanying cognitive load, may have been the true source of the reported frustration.

Given that word completion and word prediction can improve productivity, they are potentially valuable aids for the typist with a disability. However, they are also learned skills, and without adequate support from the clinician, they may be abandoned before the advantages become apparent. The majority of the participants felt that searching through the word list was tedious and distracting. Learning when and how often to scan the word list may minimize this distraction. When an individual is learning how to use the on-screen keyboard in conjunction with word prediction, it is imperative that the individual go through a training process to become proficient at using this program.

CONCLUSION

The focus of this research was to determine whether word completion or word prediction programs would increase typing speed when used with the on-screen keyboard. In past studies, as in this study, participants have indicated that the need to look away from their source material interfered with typing, even when using input methods that required looking at the input method. We first hypothesized that the addition of word completion to an on-screen keyboard would enhance typing performance as compared with the use of an on-screen keyboard without word completion. The results show that the addition of word completion to the on-screen keyboard increased typing speed for the majority of the participants in this study on the order of 7%. Because word prediction requires even fewer keystrokes than word completion does, we further hypothesized that the addition of this feature would improve typing speeds over both the on-screen keyboard alone and the on-screen keyboard with word completion. This hypothesis was also substantiated because the majority of the participants in this study had their fastest typing speed using word prediction with the on-screen keyboard, with an average gain over typing without word prediction of almost 10%. Neither of these gains are what might be expected by a keystroke savings of 30%–50%. This lag may be due to the increased cognitive load of word prediction.

Historically, word prediction and word completion have not been found to increase typing speed when using a standard keyboard or other methods of input that do not require the individual to look at the screen when generating text. This study differed from earlier work by combining word prediction and word completion with input methods that included the need to look away from a source document so that this factor would be constant. It is also possible that the improved quality of modern word prediction reduces the cognitive load of older prediction software. This study demonstrated that word completion and word prediction could increase typing speed for individuals using such input methods but that the cognitive load of the tools continues to distract users.

Despite the improved typing speeds achieved, many of the individuals in this study considered word prediction and word completion to be frustrating. This frustration may stem from the cognitive demands of scanning the word list or from the interruption in the flow of ideas when using word prediction. Further research should explore whether the frustration of using a word prediction program can be limited by different means of list presentation or through experience with the input method.

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