The ultimate intent of all assistive technology is to allow persons with disabilities to perform on an equal basis with persons without disabilities. This goal applies to all assistive technology, whether applied to allow persons to dress and groom independently or to perform job-related tasks. The unfortunate reality is that, although current technology does make many tasks possible for persons with disabilities, it does not allow their performance on an equal basis.

One example of the remaining inequality is found in systems that provide alternative access to computers. Such systems allow computer access by persons with severe physical disabilities, but generally at input rates that are markedly below those of the typist without disabilities. To provide equal access to writing and communication systems, therapists must find some means to increase the efficiency of text input. One approach to improving input efficiency is the use of word prediction software.

In concept, word prediction software is fairly simple. The word prediction program operates between the user's keyboard and any productivity program (e.g., Microsoft Word, Excel, WordPerfect). The word prediction program monitors the keys that the user types and attempts to match the characters following the most recent space with the beginning letters of words stored in an internal dictionary or word list. When the word prediction program finds likely words, it displays the matches to the user. If the word that the user is attempting to type is on that list, the user may select it from the list, and the computer completes the word. The user then begins to type the next word, and the process repeats.

Because most people use relatively few words to express most of their ideas, such software can be effective. Although the recognition vocabulary of the typical high school student may be in excess of 60,000 words (Miller, 1991), most students use fewer than that number to express their ideas. Elementary school spelling lists are derived from a list of 500 words said to represent 80% of the vocabulary of school-age children. Within a single environment, the vocabulary needs of a person seldom exceed 2,000 words.

Typical word prediction software provides an internal dictionary of 4,000 to 6,000 words. Depending on the ordering used to display the words, the user will require from 2 to 4 characters to select any word. Given the typical word length of approximately 6 characters (the average word length for this article is 6.22 letters), word prediction software offers a theoretical reduction in keystrokes of 50%. In theory, this reduction in keystrokes should correlate with an increase in speed of input, provided that the word prediction software is able to enter words faster than the typist. In practice, the limited acceptance of word prediction software by users without disabilities suggests that the advantage is not as great as expected.
The rehabilitation literature offers little evidence to document the advantages or limitations of word prediction software. MEDLINE lists only two articles describing input enhancement software. One study (Smith et al., 1989) compared the mechanical efficiency of a pointing input system that incorporated word prediction with the efficiency of no writing system for persons with severe physical disabilities. This study demonstrated that writing speed is better with the combination of long-range optical pointer and word prediction software than with no writing system. It did not, however, separate the effect of word prediction from the effect of the pointing input system. Another article (Angelo, 1988) described the features of an abbreviation-expansion program without exploring its clinical application. Although these articles documented the interest in keyboard enhancement, they do not support an expected increase in speed of text input. In this study, combining the demonstrated gains in mechanical efficiency through reduced keystrokes with the observed poor acceptance of word prediction by the mass-market computer user, I explored the relationship of word prediction to typing speed.

Method

This study used a single-subject, ABC design to test word prediction with two types of computer input: conventional keyboard input and on-screen keyboard input.

Subjects

The 18 subjects for this study were recruited by advertisements posted in the University of Washington Health Sciences Center. All subjects were between the ages of 18 and 55 years, with vision adequate to use a standard computer monitor. Ten subjects (8 women and 2 men) were assigned to the touch-typing group; eight subjects (6 women and 2 men) were assigned to the on-screen keyboard group. All 18 subjects had prior experience using keyboards. No prior typing or computer use was required for participation in this study; however, subjects could not have had significant experience with word prediction software.

Equipment

For the conventional keyboard input sessions, the study used an IBM PS/2 Model 70 computer1 with the standard IBM keyboard, Microsoft Word 5.5,2 and HandiWord™ word prediction software.3 The display screen was an IBM 8513 VGA monitor,4 mounted on top of the computer's IBM keyboard, Microsoft Word 5.5, and HandiWord package counted the number of words selected in the second and third trials. This word count was not available for the Macintosh on-screen keyboard.

Procedure

Of the three primary styles of typing (typing from copy, typing from dictation, and free composition), only typing from copy would be immediately understood by the subjects and could be standardized. Free composition, by its nature, is not easily standardized. Typing from dictation would add to the study the use of a dictation machine, another variable that would be difficult to control. Because of these factors, this study focused on typing from copy, which, except for transcriptionists, may be the most common form of typing. Testing for each subject was completed in a single session ranging from 30 to 60 min, depending on the typing speed of the subject. At the beginning of each session, the subject was asked to review a consent form that described the intent of the study, the test procedure, and the possible risks of the study. The subject was given the opportunity to resolve any questions about test procedure before testing began.

The typing text for all sessions was taken from the Gettysburg Address. For the conventional keyboard sessions, subjects typed the entire address. For the on-screen typing session, subjects typed only the first 118 words of the address, to control for fatigue effects. The reduced text resulted in overall typing times that were similar to those of the conventional keyboard subjects, and compensated for the generally slower typing rate of on-screen keyboards. In all sessions, the text was provided in the plane of the computer monitor, mounted on a copy stand to the left of the computer screen.

1Manufactured by International Business Machines Corporation, Armonk, New York 10504.
2Manufactured by Microsoft Corporation, One Microsoft Way, Redmond, Washington 98052-6399.
3Manufactured by Microsystms Software, Inc., 600 Worcester Road, Framingham, Massachusetts 01701.
4Manufactured by International Business Machines Corporation, Armonk, New York 10504.
5Manufactured by Apple Computer, Inc., 20525 Mariani Avenue, Cupertino, California 95014.
6Manufactured by Microsoft Corporation, One Microsoft Way, Redmond, Washington 98052-6399.
7Manufactured by Berkeley Systems, 1700 Shattuck Avenue, Berkeley, California 91709.
8Manufactured by McIntrye Computer Systems, 22809 Squak Hill, Suite 101, Bingham, Michigan 48010.

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The session consisted of three typing phases. In the A phase, the subject was instructed to type the stimulus text "as you normally would." In response to queries about correcting misspellings, the instruction to type "as you normally would" was repeated. The subject was timed from the signal to begin until the keystroke of the final period of the text. When the subject had finished typing, the experimenter gave an opportunity to rest.

At the beginning of the B phase, the subject was introduced to the word-prediction features of the software. A special vocabulary had been prepared for the word-prediction packages that contained just the words of the Gettysburg Address, so the subject was not confronted with extraneous words. The subject was instructed to use word prediction "as much as possible" to find all the words he or she could using the word-prediction package and to select them from the prediction list. Again, timing began with the signal to begin typing and ended with the keystroke at the final period of the text.

For the C phase, the subject was instructed to use the word-prediction list selectively, "whenever you think it will speed up your typing." When the subject thought that typing a word would be faster than selecting it from the prediction list, he or she was free to do so. Timing was as in the first two phases.

At the end of the session, the subject was asked which features of word prediction were helpful and which were difficult to use. This procedure was intended to offer maximum advantage to word-prediction software and to simulate the effect of familiarity on typing speed. In discussions of word-prediction efficacy, it is often argued that speed improves with practice. Testing the most likely mode of word-prediction use (selecting words only when it will improve speed) last gave each subject equivalent prior experience. Because all subjects were novice users of word prediction, this approach indicates the results that might be obtained by experienced users in a less optimized environment.

To control for possible learning effects, each subject was tested on only one variety of input and word-prediction. Subjects who used the conventional keyboard input were not also tested on the on-screen keyboard input.

**Results**

*Conventional Keyboard Input*

The typing skills of the 10 subjects using conventional keyboard input varied considerably. Average typing speed was 49.55 words per minute, with a minimum speed of 24.14 words per minute and a maximum of 72.11 words per minute. As might be expected, when subjects were asked to use word prediction for all words of the text, their typing speed dropped markedly to an average of 13.95 words per minute. However, when subjects were asked to use word prediction only when it would speed up input, typing speed recovered.

In 3 cases, the typing speed with selective word prediction was as fast as or faster than typing speed with no word prediction. The number of times word prediction was used by these subjects for the 268-word passage was 0 for Subject 4, 1 for Subject 8, and 4 for Subject 10 (see Table 1). For the remaining 7 subjects, typing speed decreased. When instructed to use word prediction only when it would increase typing speed, these subjects' speed decreased in proportion to the number of words selected ($r^2 = .744, p = .003$). When asked what feature of word prediction most affected typing speed, 8 of the 10 subjects stated that having to look away from the text being typed caused them to lose their place.

*On-Screen Keyboards*

The results for the on-screen keyboard group were different from those of the conventional keyboard group. Novice users of on-screen keyboards found them much slower than touch-typing. When typing with no word prediction, the mean typing speed for the 8 subjects was 8.7 words per minute. When typing with word prediction and instructed to use the word prediction as often as possible, typing speed increased in each subject. The mean typing speed was 9.4 words per minute. When instructed to use word prediction selectively, 7 subjects increased their typing speed even further and 1 subject decreased slightly. Overall, the mean typing speed increased to 11.2 words per minute (see Table 2).

**Discussion**

The results of this study must be considered in light of its limitations as a single-subject design with a relatively small number of subjects. As such, some care must be taken when generalizing the results to the general population. The present study examined only the copying of text into a computer. Future studies should explore the effect of word prediction for typing from dictation tapes and on free composition.

An unstated assumption of word prediction is that, for slow typists, word prediction will increase typing speed, but that this improvement disappears as typing...
speed increases. It has been suggested in presentations on word prediction that the critical typing speed above which word prediction fails to produce gains is between 15 and 20 words per minute. The results of this study did not support this assumption. For touch typists working from hard copy, word prediction software offers no speed advantage regardless of typing rate. It does offer a savings of keystrokes, with an associated savings in energy expenditure. However, this advantage, for the touch typist, is at the cost of typing speed.

Many discussions of the effect of word prediction have focused on the relative time used in scanning the word prediction list versus the time spent typing a word. These discussions have overlooked the effect of looking away from copy. In this study, the touch typists reported that looking away from the source copy to scan the word selections caused them to lose their place. The time required to locate their place in the stimulus text more than outweighed the savings in typing time that word prediction might offer. The relationship between the number of words selected and the decrease in speed suggests a fairly constant delay per word selected.

This effect was borne out in the results of the on-screen keyboard tests. Using an on-screen keyboard requires the typist to look away from the text to use the keyboard. Although this input method continues to require the user to scan the word-prediction list, this requirement is separated from the need to look away from the text. Under these conditions, using word prediction for all words of the text, hence scanning for each word, increased input rates over no word prediction. The speed gained by automatic typing was greater than the time taken to scan the word prediction lists. For conditions for which the typist was free to select only those words where an increase in speed was expected, thus reducing the effect of scanning for words, the improvement was even greater. Under this mode, the need to look away from the screen remained constant, and only the scanning time changed between phases B and C.

The most pronounced effect of word prediction for touch typists was the need to look away from the source copy. This result may be different when word prediction software is used for novice typists, who look at the keyboard to find keys. However, the result also suggests that input methods that force the user to look away from source copy may intrinsically reduce typing speed. This is consistent with the insistence in introductory typing classes that students not look at the keyboard when typing.

On the other hand, when a typist must look away from the text to type, the speed enhancement of word prediction becomes evident. Although the current study explored the effect of word prediction only on direct word selection methods, the results may generalize to other on-screen methods (e.g., scanning input). For other input methods that do not require the user to look away from the text (e.g., Morse code), word prediction may also reduce typing speeds.

### Conclusion

The results of this study, which focused on the effects of word prediction on typing speed when working from printed text, should not be generalized to typing from dictation tapes or free composition. Because neither of these alternative typing styles involves visually tracking a source document, the typist would not have to look away from the source. However, for students and for many workers, a large fraction of typing will be done from printed drafts. For this kind of typing, the study results suggest guidelines for the use of word prediction software.

Where the primary goal of enhancement software is to reduce the physical effort of typing, and where the effort of using the keyboard is a major component of the fatigue of typing, then word prediction is indicated, provided that speed is not an overwhelming issue.

When the user is able to type without looking away from the draft text, it is unlikely that word prediction software will enhance typing speed. For touch typists working from draft text, the use of word prediction slows down typists in proportion to the frequency of use of the prediction list. If the cause of this slowing is that reported by the subjects in this study (the effort to find their place after scanning the prediction list), then the results should generalize to other encoded input modes. However, when the user must look away from the stimulus text to type, as with on-screen keyboards and scanning arrays, word prediction software offers a great speed enhancement, and ought to be provided to the user who is able to use it.

### References

