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ABSTRACT

Computer reading machines that convert printed material into speech can provide substantial assistance to many people with learning disabilities who have poor reading skills. They can enhance their reading rate and comprehension and increase the length of time that reading can be sustained. A new generation of computer reading machines now have become available that provide a substantial improvement in the way in which printed material is displayed. They allow user to see an accurate image of the page being read including illustrations, layout, and formatting in addition to the text. The quality of the synthesized speech is improved and facilities for enhancing comprehension and critical reading are provided. We have studied the efficacy of one of these reading machines, the Kurzweil 3000, in enhancing reading performance of a group of community college students. The results of this study presented in this article include models that can be used to predict the enhancement in reading performance that individuals can expect based upon tests of unaided reading and oral language skills.

INTRODUCTION

People who are poor readers because of dyslexia or other learning disabilities report that reading is slow, inaccurate, and hard work. To extract meaning from text, they usually find that they have to proceed slowly, re-read passages frequently, struggle to decode unfamiliar words, and interrupt their reading frequently to recover from fatigue and stress. Since they read slowly and intermittently, reading takes them much more time than it does their peers at school or their colleagues at work. As a result, the quantity of material that they read is small, and since they get much less practice reading, they have less opportunity to improve their reading skills. In secondary school, students with these difficulties often do not have the time, energy, or motivation to read course material and often must depend upon family or tutors to help them with their reading. As a result, they may do poorly in their courses or become dependent upon others to achieve academic success. At college, the amount of reading required is greater and family support is often less available, and they may simply run out of time to complete their work.

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Many people with poor reading skills have a relatively good ability to handle spoken language. They can process speech at normal or even fast rates, their receptive vocabulary is good, and their comprehension of oral language is excellent. For this group, computer reading machines can be of great help. Reading machines convert printed text into speech. The conversion is accomplished by a speech synthesizer that produces speech from the words and punctuation stored in a text file in the computer's memory. A computer reading machine can speak essentially any text, and current systems do so with excellent fidelity. By using a reading machine, a person with poor reading skills, but good receptive language skills, can listen to the text as well as see it on the computer monitor and may be able to "read" faster, with better comprehension, and with less stress and fatigue.

Computer reading machines can handle text from almost any good quality printed document (*e.g.*, books and magazines) or from computer documents such as those created with word processors, electronic mail, or on web pages. Printed documents are placed on a scanner (which is like a copier), and the text is recognized by a character recognition program and converted into a form that the synthesizer can use to produce speech. Computer text simply needs to be converted from the format used by the program that created it (*e.g.*, word processor, electronic mail system, web page format) into the form appropriate for the speech synthesizer.

Computer reading machines designed for people with reading disabilities show the page to be read on the computer monitor while it is spoken. As the text is spoken, it is highlighted on the monitor so that the correspondence between the printed words and their sound is reinforced. Providing the user with this synchronized visual and auditory presentation of the text in the document is a key idea of computer reading machines.

Reading machines offer considerable flexibility in how information is presented. The user with can control the speed at which the text is spoken, the voice pitch, and the quality of the speech. The type of highlighting (word, phrase, line, or sentence), how much text is spoken without pausing (word, phrase, sentence, paragraph, or entire document), and the colors used for displaying the document and for highlighting are all under user control.

Commercial products providing some of these capabilities have been available for several years (Xerox, 1993; Arkenstone, 1993). A major limitation of these earlier systems was that they presented only the unformatted text from the document being read. Pictures, graphics, page layout. and text formatting were lost. The text was displayed in a linear form as if it on a scroll. As a result, these products were limited largely to reading simple documents such as novels. They were difficult or unsatisfactory to use for reading history, science, and other text books which have many illustrations, complex layouts and text formatting.

Not only were the illustrations missing, but to navigate around the page to read side bars, figure captions, and headings it is necessary to see where these objects are located in the two dimension space of the page.

This limitation was overcome in 1997 when Kurzweil Educational Systems introduced a product, the Kurzweil 3000 (Kurzweil, 1997), in which an image of the actual page with pictures, graphics, page layout. and text formatting faithfully reproduced in color is shown on the computer monitor. The text on this page image is highlighted as it is being spoken. This product is effective for reading complex materials such as text books.

The Kurzweil 3000 and another recent product from Arkenstone (WYNN) provide other major improvements. The accuracy of the character recognition and the fidelity of the speech produced by the synthesizer is better. Study tools that enhance the reader's ability to gain meaning from the document and to read critically are provided. These tools enable the user to do things such as preview a document, take notes, mark important parts of the document, look up a word in a dictionary, and obtain the syllabification and pronunciation of a word that is selected.

A number of studies have been conducted of the efficacy of reading machine technology in enhancing the reading performance of people with dyslexia and other learning disabilities. These studies revealed that not all people with reading disabilities benefit from using reading machines to compensate for their poor reading skills, and that the benefits that people do obtain vary considerably. For example, in a study of middle school students with dyslexia (Elkind et. al., 1993), we found that most of the children enhanced their reading comprehension test scores, some with very large gains, when using a computer reader. However, other children actually experienced degradation in reading. Higgins and Raskind (1997) obtained a similar result in their study of post-secondary students and observed that enhancement in reading comprehension test scores was inversely related to unaided comprehension scores. That is, poor readers seemed to benefit more from the technology than better readers.

We undertook a second study with adults (Elkind et. al., 1996) to investigate the effects on reading rate and ability to maintain and to identify the characteristics of individuals who were most likely to benefit from the technology. This study was motivated in part by our observation that many of the children in our middle school study appeared to be able to attend to a reading task longer when using the computer reader than when reading unaided and that many reported increases in their reading rate. We found significant gains in reading rate and attention in our study with adults and identified certain standard diagnostic tests that were helpful in predicting who would benefit from the technology and by how much. Thus, as a result of research that we and others have done (*e.g.,* Higgins and Raskind, 1997; Leong, 1992, 1995) we can describe the characteristics of the individuals that are likely to benefit and quantify to some extent the benefits that they are likely to experience.

Although the discussion in this paper focuses on the use of reading machines to compensate for poor reading skills, the technology has also been used in instructional programs aimed at improving reading skills. Studies by Olson, Wise and their colleagues (Olson, Foltz, and Wise, 1986; Olson and Wise, 1987; Olson and Wise, 1992; Wise and Olson, 1995), by Torgesen and his colleagues (Torgesen and Barker, 1995), Lundberg and Olofsson (Lundberg, 1995; Lundberg and Olofsson, 1993), discuss interesting results.

MEASURING READING PERFORMANCE

The remainder of this article discusses how computer reading machines help post-secondary students with poor reading skills read better. This discussion is based largely on a recently completed study (Elkind, 1998) investigated the efficacy of one of the new generation of reading machines, the Kurzweil 3000. It is a follow-up to our previous studies of middle-school students and adults with learning disabilities that were done using a predecessor product, the Xerox BookWise reader (Elkind et. al., 1993 and 1996).

Three components of reading performance were the focus of this study: speed, comprehension, and factors (such as stress and fatigue) that might influence endurance (*i.e*., time-on-task). We wanted to determine how computer reading machine technology affected these components of performance. We used standardized reading tests to measure reading speed and comprehension. We obtained information about factors affecting endurance from structured interviews and questionnaires, since direct measurement requires long term observation or difficult physiological measurements of fatigue, stress, and workload. We measured reading performance when participants read both with and without the aid of the Kurzweil 3000 reading machine.

The Nelson Denny Reading Test (Brown, Bennett, and Hanna, 1981) was used in our studies. This standardized test for grades nine through senior year in college requires the participant to read a series of passages on different subjects and answer a set of questions after reading each passage. A comprehension score is obtained from the number of questions answered correctly in a 20 minute period. We allowed our participants to continue reading beyond this prescribed time limit so that we could obtain both a timed and an untimed comprehension score. A reading rate (speed) score was obtained from the number of words read during the first minute of the test.

We also obtained scores on four components of the Wechsler Adult Intelligent Scale (WAIS) (Wechlser, 1974) and the Woodcock-Johnson Psycho-Educational Battery-Revised (WJ) (Woodcock and Johnson, 1989) that our earlier studies had indicated were useful predictors of the effect of reading machine technology on reading performance. The components were: the WAIS Vocabulary and Comprehension component and the WJ Memory for Sentences and Picture Recognition.

Participants in our study were 26 students from De Anza Community College in Cupertino, CA who were diagnosed as "learning disabled" using a California system-wide discrepancy-based definition of learning disabilities adapted from the National Joint Committee on Learning Disabilities (Hamill, Leigh, McNutt, and Larsen, 1981). They were interviewed, then given several diagnostic tests of cognitive function (unless results from earlier administrations of these tests were already in their files), trained to use of the Kurzweil 3000 for about an hour, and finally tested with and without the Kurzweil 3000 to determine how it affected their reading. Different forms of the test were used in the aided and unaided conditions. Care was exercised to balance the order of conditions and the forms used so that the results would not be biased by these factors.

UNAIDED READING PERFORMANCE

In the pretest interviews and questionnaires the participants offered the following assessment of their reading problems:

- 70% reported that they were slow readers
- 75% reported poor comprehension
- 75% reported that they could maintain attention on reading for only short periods of time, 30 minutes or less, before attention wandered and they would need to take a break, or stop. For 45% their endurance was 15 minutes or less.

Nelson-Denny tests of unaided reading performance gave results that are consistent with this self assessment. If anything, the self-assessments were optimistic. The Nelson-Denny allows us to determine where a participant ranks relative to others at the same grade level in reading rate, and timed comprehension, and how the comprehension ranking would change if unlimited time were allowed.

Reading rate was clearly a major problem for the participants in our study. Their unaided rate is very slow compared to that of their peers . Their median reading rate was only 149 words per minute (wpm). This compares to a median of about 250 wpm for community college students. Thus half of the participants were reading at less than 60% of the speed of most of their educational peer group. The median percentile ranking of the participant group was at the 12th percentile of the population used to standardize the Nelson Denny test. That is, half of the participants read more slowly than 88 percent of their grade-equivalent peer group.

About 25% of the participants had reading rate scores at or below the 5th percentile of their grade-equivalent peer group, that is 25% of the participants read more slowly than 95% of their peer group. Their reading rates were 110 wpm or less, that is, less than 45% of the median of community college students. Reading would take them two times longer than most of their peers.

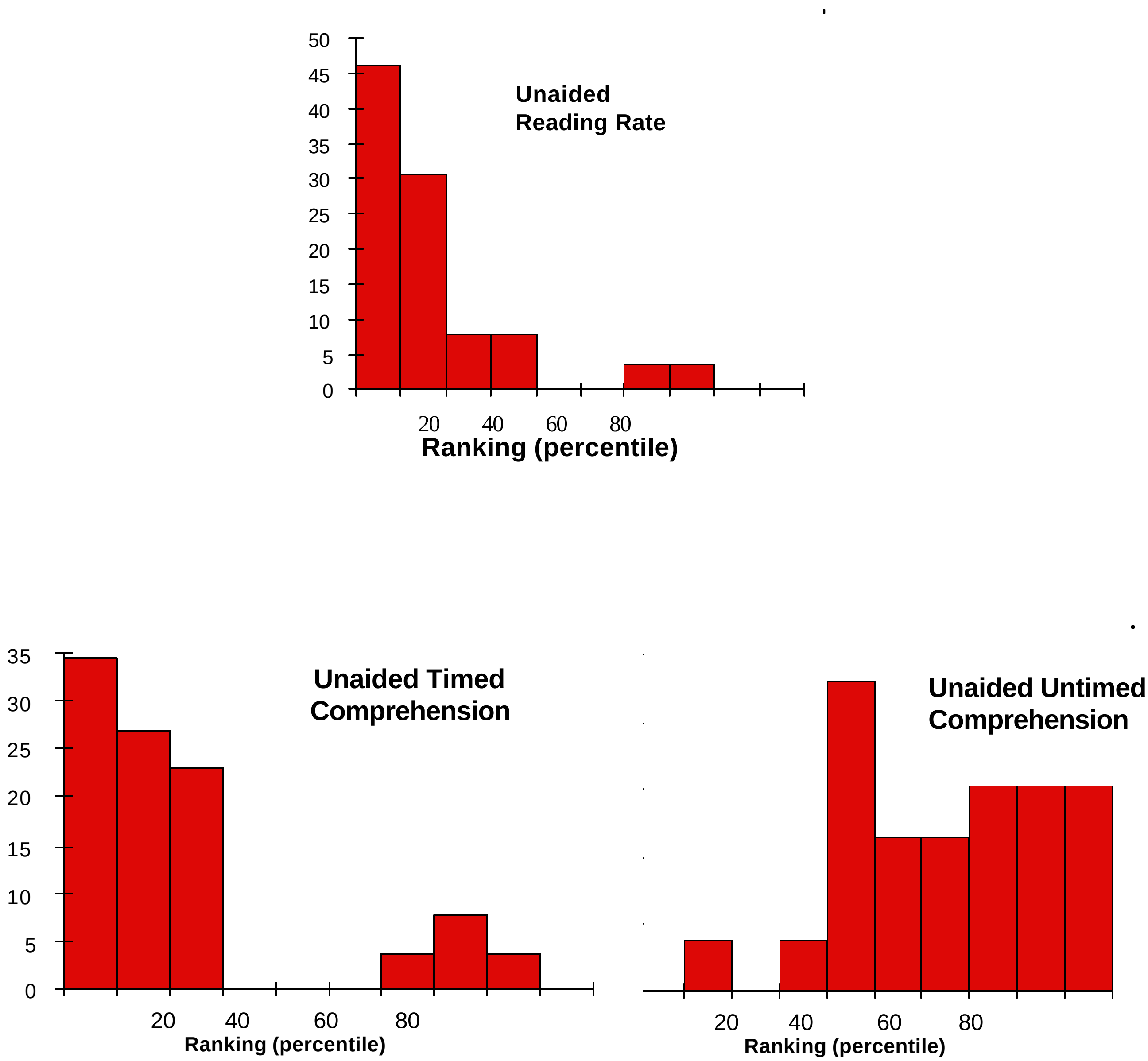


Figure 1. Distributions of percentile scores for the unaided reading rate of participants. The percentiles rank the participants in our study relative to national reference groups who were at the same grade level as each of the participants. The median reading rate was 12th percentile (149 wpm). The median reading rate for community college students is 250 wpm.

The slow reading rate is compounded by the fact that many of the participants could not sustain reading for very long. Thus not only do they read slowly when they read, but they do not read for long periods of time without taking a break. It is not surprising that many dyslexic college students comment that running out of time was their critical problem at school. Given their slow reading rates, they simply did not have time to complete the reading required of them; to keep up they would have to spend two to three times more time than their peers.

The effects of slow reading are evident in the comprehension scores. The median timed comprehension score was at the 15th percentile; that is, half of the participants had timed comprehension scores that placed them at or below 85 percent of their grade-equivalent peer group. When they were allowed to continue beyond the time limit, they did considerably better. The median of their untimed scores increased to the 64th percentile. Thus, when given more time, our participants, as a group, had comprehension scores that were roughly on a par with, or slightly better than, their peer group. They appear to have adopted strategies for reading slowly, and often re-reading, to achieve an effective comprehension level. When constrained by time, their scores are low. If additional time is allowed, they do reasonably well.

EFFECT OF THE READING MACHINE ON READING SPEED

When the participants used the Kurzweil 3000, those whose unaided reading was slow increased their reading rate substantially, while those whose unaided reading was fast read more slowly. This inverse relationship is clear in the scatter plots of Figure 2 which show the difference between the aided and unaided reading rates (?Rate) plotted against the each participant’s unaided reading rate.

Unaided reading rate is a very good predictor of who will benefit in terms of increased reading rate from reading machine technology. A simple linear model represented by the regression line in Figure 2 accounts for 80% of the variance in ?Rate (correlation, $r^2 = 0.80$). This regression line has a slope of -0.92 and intercept the x-axis at 176 wpm, which is approximately the speed of normal speech. The regression model predicts that individuals with an unaided reading rate less than 176 wpm will read faster with Kurzweil 3000; those with an unaided rates greater than 176 wpm will have degraded performance

The fact that the regression line has a slope of -0.92 indicates that the participants in our study were able to “recover” about 92% of the difference between their unaided rate and the intercept rate of 176 wpm, thereby making the aided reading rate closer to that of normal speech. For example, an individual who read unaided at 76 wpm (100 wpm less than the x-intercept) could expect a 92 wpm enhancement in reading rate to

168 wpm, more than doubling his or her unaided reading rate . Two of the participants in our study had reading rates that were this slow; both experienced gains of 100 wpm.

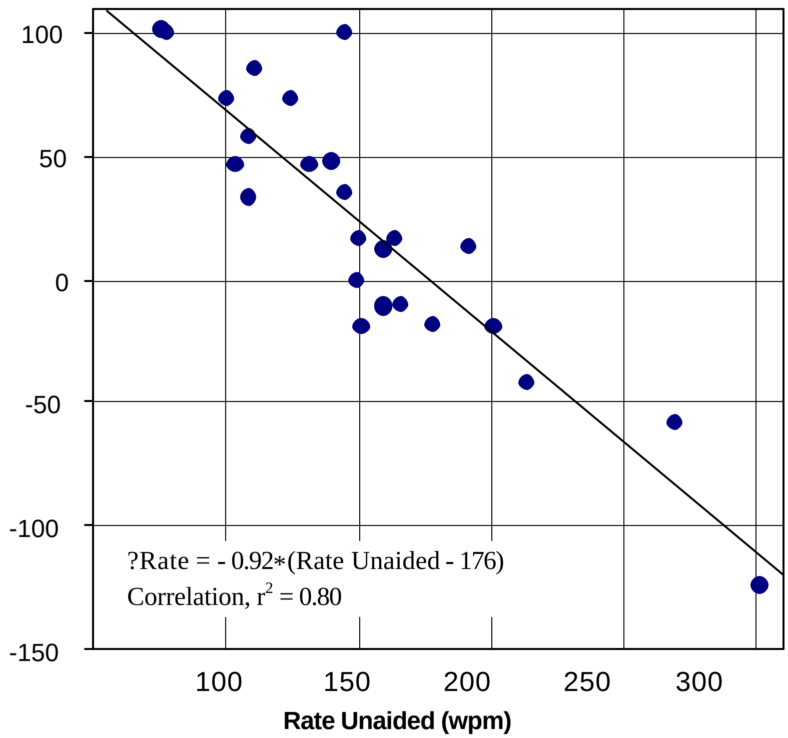


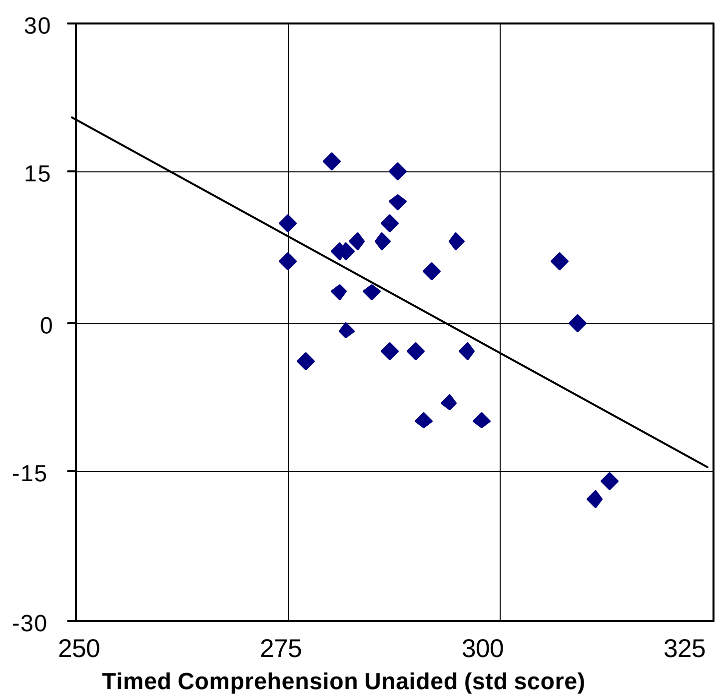
Figure 2. The changes in reading rate that result from use of Kurzweil 3000 depend upon the participants' unaided reading rate. The negative regression line shown on the scatter plot indicates that participants having the slowest unaided reading rate are likely to benefit most.

As users gain experience with the speech synthesizer they may become comfortable having it speak at higher rates and be able to increase their aided reading rate still further. We had reports that this did occur for some participants of our earlier adult study who were able to use a reading machine for extended periods.

EFFECT OF THE READING MACHINE ON COMPREHENSION

The results for timed and untimed comprehension are similar. There is an inverse relation between benefit obtained from using the Kurzweil 3000 and unaided comprehension scores. Those who had poorer unaided scores obtained greater benefit than those whose unaided comprehension was better. The results, summarized in the scatter plots and regressions lines of Figure 3, are similar to those we obtained in our earlier adult study and to results obtained with post-secondary students by Higgins and Raskind (1997)

The comprehension data have more scatter than the reading rate data, and a simple regression model does not account for as much of the variance. The regression models account for only 33 percent of the variance for timed comprehension and 37 percent for untimed comprehension. The x-intercept is about 294 standard score for the timed comprehension and about 311 standard score for the untimed comprehension. The median standard score of 10th grade high school students in the Nelson Denny timed comprehension test is about 294. Thus, participants whose unaided comprehension is poorer than that of 10th graders are likely experience gains in (timed) comprehension from the use of the Kurzweil 3000.



?Comp = - 0.48∗(Comp Unaided - 294)
Correlation, $r^2 = 0.33$

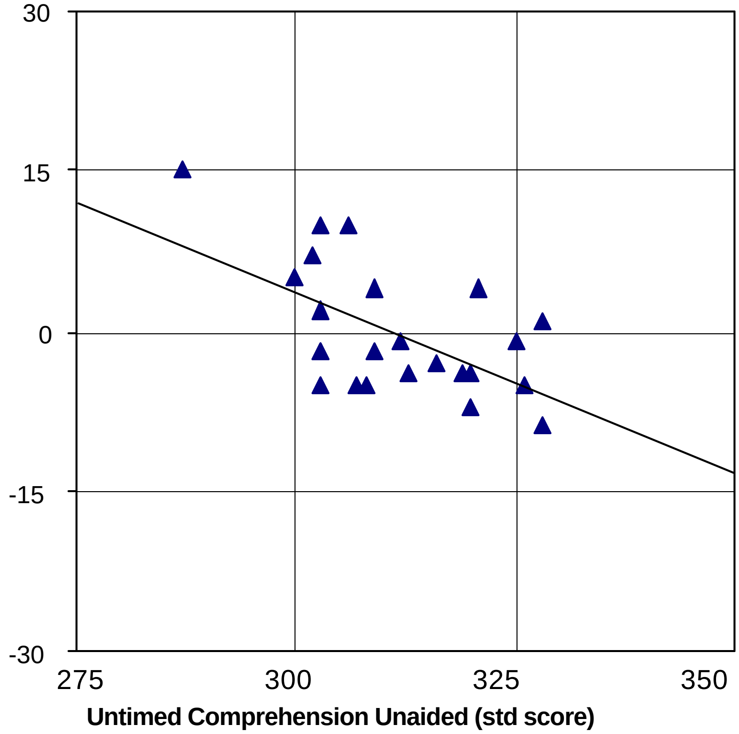


Figure 3. The changes in unaided comprehension scores that result from the use of the Kurzweil 3000 also depend upon unaided … *comprehension tend to benefit most.*

?Comp = - 0.35∗(Comp Unaided - 311)
Correlation, r^2 = 0.37

A better prediction of benefit can be obtained by combining the unaided comprehension scores with the results from the WAIS Vocabulary test in a multiple regression model. Figure 4 which shows the actual changes in comprehension plotted against those predicted by the regression models. The equations for the models are in the figures. The multiple regression models using both of the unaided comprehension scores and the WAIS Vocabulary score account for more of the variance than did the simple model based only on the unaided comprehension scores. This can be seen by comparing the correlations, r^2, shown in Figures 3 and 4.

These models indicate that participants whose unaided comprehension standard scores are less than 293 for timed comprehension and 313 for untimed comprehension and who score better than the mean of 10 on the WAIS Vocabulary test are likely to benefit from the reading machine technology. The WAIS Vocabulary test is a test of oral vocabulary in which the participant is required to give definitions of spoken words ranging from those with concrete meanings to those that are more abstract. It measures understanding of spoken words, general range of ideas, and verbal information acquired from experience and education, and the kind and quality of spoken language (Compton, 1984). The regression models suggest that individuals with good ability to process oral language as measured by the WAIS Vocabulary test will benefit more from the reading machine t than those who with poor scores on this test. It seems entirely reasonable that good oral language ability would have this effect.

To illustrate how these models can be used to predict the effect of the reading machine on performance, consider the results from one of our participants. His unaided reading rate was 132 wpm. The model in Figure 2 predicts that his rate would increase to 174 wpm; this is very close to the observed increase to 178 wpm. His unaided timed comprehension score was 282 which is substantially lower than crossover score of 293, so we might expect a large gain in comprehension. However, his Vocabulary score was only 6, low compared to the average of 10, and this offsets the effect of the low unaided comprehension score. The model for timed comprehension in Figure 4 predicts that there will be negligible change in comprehension score as was in fact the case. Of course the models do not predict the effects this closely for all participants. The model for reading rate, because it accounts for a large fraction (80%) of the variance in the data, provides better predictions than do those for comprehension.

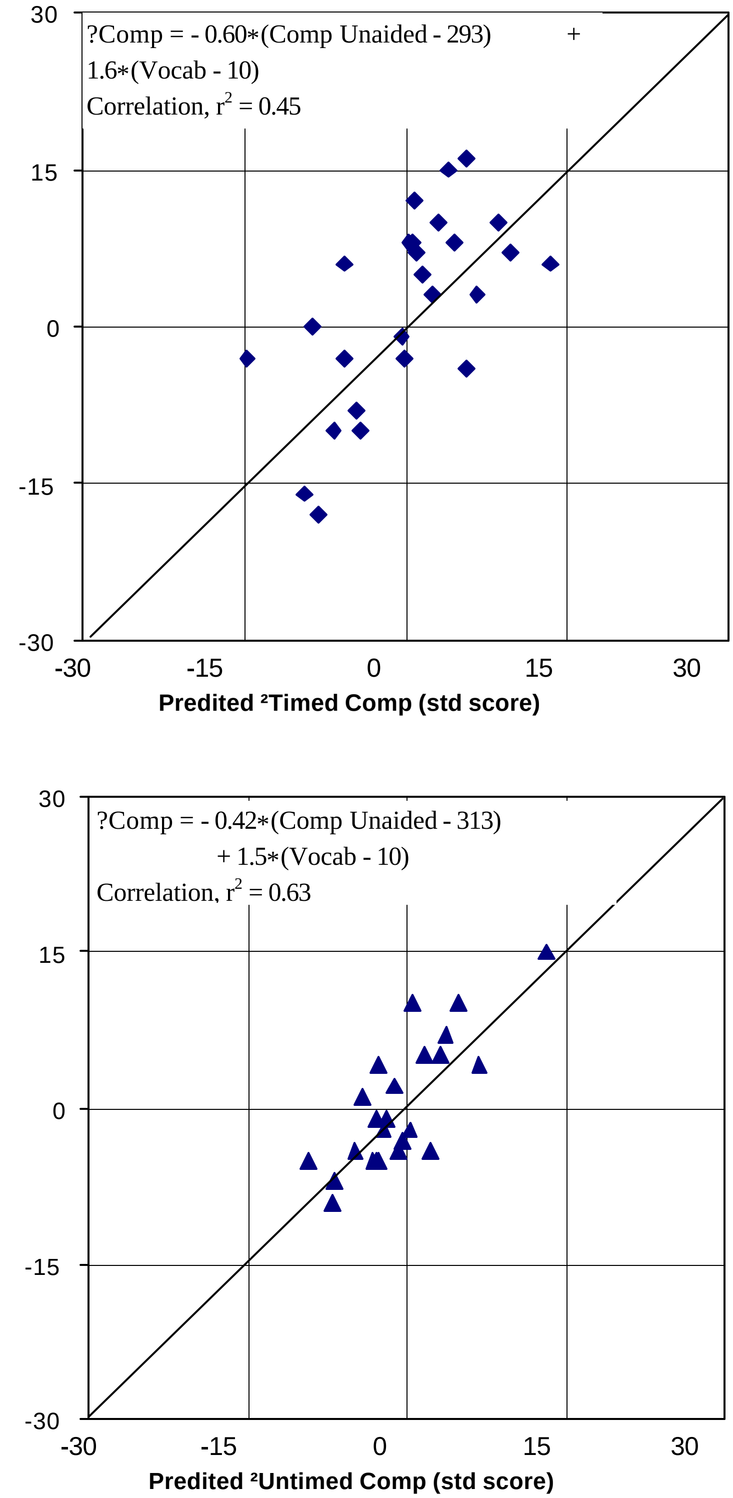


Figure 4. Comparison of actual change in timed and untimed comprehension scores and predicted values obtained from multiple regression models incorporating unaided scores and the WAIS Vocabulary test scores.

EFFECT OF THE READING MACHINE ON ENDURANCE

In our earlier study of reading machine technology done with the BookWise system from Xerox, we gave fourteen participants computer readers to use for an extended period of time for school and work reading. They used the readers for from three months to a year. All but one of the participants, 91%, reported that they were able to increase the time that they could sustain attention (endurance) while reading before their attention wandered or before they had to take a break. They reported increases in endurance by factors of two and three. This result is especially important since most of these participants reported in pre-testing interviews that they had difficulty reading for extended periods; some could not even read for 15 minutes, and seventy-five percent reported a limit of half hour or less.

PARTICIPANT EVALUATION OF THE READING MACHINE

The participants were given a structured questionnaire after they used the Kurzweil 3000 in which we asked them for their personal evaluation of the reading machine and how it affected their reading performance. Their responses are summarized in Table I.

Almost three-fourths of the participants thought that reading was less tiring and less stressful when using the Kurzweil 3000. Only one of the participants thought that Kurzweil 3000 would make reading more tiring. This is probably the reason that so many of the participants (73%) thought it would help with their school reading and that all except two (85%) stated they would like to use Kurzweil 3000 for their reading. It is also an indicator that the reading machine should enable greater reading endurance. Fatigue and stress certainly contribute to making reading hard to sustain..

Only three (12%) of the participants indicated difficulty integrating auditory and visual information provided by the reading machine. Two of these three participants were also ones who felt that the reading machine did not help reduce stress associated with reading and that they did not think it would help with their reading. One of them reported great difficulty integrating auditory and visual information and did not want to use the reading machine.

TABLE I. PARTICIPANTS' EVALUATION OF KURZWEIL 3000 AFTER BRIEF USE

Question	Percent agreeing	Percent disagreeing	Percent neutral
reading less tiring?	73%*	4%	23%
reading less stressful?	73%*	19%	8%
auditory/ visual integration difficult?	12%	62%	27%
Reading machine would help with school reading?	73%*	12%	15%
Would like to use reading machine for reading?	85%**	8%	8%

The number (n) of participants responding to questionnaire was 26.
** indicates significance at the .01 level.
* indicates significance at the .05 level.
The one sample sign test (with ties counted) was used to test the null hypothesis that the median response was equal to no change or neutral.

SUMMARY

Computer reading machine technology can provide substantial assistance to many people with learning disabilities like those in our group of poor readers. It can enhance their reading rate and comprehension (timed and untimed) and increase the length of time that their attention to reading can be sustained. It can make reading less stressful, and less tiring and almost all participants indicated that they would like to use the Kurzweil 3000 for their reading and that they thought it would help with their school reading. The technology, however, does not help all poor readers. Those who have difficulty integrating the auditory and visual information provided by the reading machine and those who read faster than conversational speech or who have relatively good comprehension often find that it degrades their reading.

People whose reading speed, comprehension, or endurance improves when they use computer reader technology tend to have the following characteristics:

- *Poor unaided reading rate, comprehension, or endurance.* That is, they have a serious problem reading. Unaided reading rate alone provides an excellent prediction of the gain that can be expected in reading rate when the reading machine is used.
- Good oral language capabilities as measured by a diagnostic test such as the WAIS Vocabulary test. This test used in conjunction with the an unaided reading comprehension score from a test such as the Nelson-Denny can be used to predict the gain in comprehension that can be expected when the reading machine is used.
- *Good ability to integrate auditory and visual information.* This is a key requirement for being able to take advantage of the essential feature of the technology: simultaneous spoken and visual presentation of text.

When these conditions are satisfied, computer reading machines are likely to enhance the reading performance of individuals with learning disabilities and make reading more pleasurable. It is a tool that will allow them to read at a level more commensurate with their intellectual ability and that will help them attain their goals at school and at work. This is true now and will become even more so in the future as this technology becomes more capable and less expensive.

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