Speaking to Read: The Effects of Speech Recognition Technology on the Reading and Spelling Performance of Children with Learning Disabilities

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In recent literature on persons with learning disabilities (LD), speech recognition has been discussed primarily as an assistive technology to help compensate for writing difficulties. However, prior research by the authors has suggested that in addition to helping persons to compensate for poor writing skills, speech recognition also may enhance reading and spelling; that is, what was designed as assistive technology appears to serve remedial functions as well. The present study was conducted to determine whether elementary and secondary students with LD who used the technology to write self-selected compositions and class assignments would demonstrate improvements in reading and spelling. Thirty-nine students with LD (ages 9 to 18) participated. Nineteen participants used speech recognition 50 minutes a week for sixteen weeks, and twenty students in a control group received general computer instruction. Results indicated that the speech recognition group showed significantly more improvement than the control group in word recognition ($p < .0001$)*, spelling* ($p < .002$) *and reading*

Annals of Dyslexia, Vol. 49, 1999
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ISSN 0736-9387

comprehension ($p < .01$). Pre- and posttests on five reading-related cognitive processing measures (phonological, orthographic, semantic processing, metacognitive reading strategies, and working memory) indicated that for the experimental group, only phonological processing improved significantly over the treatment period when compared to controls ($p < .04$). Further ANCOVA suggested that growth in phonological processing was associated with significant differences among conditions for all three academic measures: word recognition, spelling, and reading comprehension.

Interest in assistive technology for individuals with learning disabilities (LD) has grown dramatically over the last several years (Bryant and Bryant 1998; Bryant and Seay 1998; Elkind, Black, and Murray 1996; Higgins and Raskind 1995; Lewis 1998; MacArthur 1996; McNaughton, Hughes, and Clark 1993; Raskind 1994; Raskind and Higgins 1995a, 1995b). According to the Technology-Related Assistance Act of 1988 (P.L. 100-407, Stat., 1046, p.102), assistive technology refers to "any item, piece of equipment, or product system, whether acquired commercially off-the-shelf, modified, or customized, that is used to increase, maintain or improve the functional capabilities of individuals with disabilities." Assistive technology for persons with LD can further be delineated as any technology that enables an individual with LD to compensate for specific deficits. In some instances, the technology may assist or augment task performance in a given area of disability, whereas in others it is used to circumvent or bypass specific deficits entirely. Furthermore, assistive technology compensates for weaknesses by "playing to" an individual's area(s) of strength. It is not intended to "fix" or remediate LD, nor to teach or instruct (as is computer-aided instruction).

Elsewhere, we have stressed that educators must have a clear understanding of the differences between assistive and remedial technologies in order to ensure that they are employing the proper technological interventions to reach their specified educational goals (Raskind and Scott 1993), and to implement technology in an ethical manner (Raskind and Higgins 1995b). Despite the necessity of distinguishing between the two approaches, they need not be considered mutually exclusive. There is no reason why technologically based compensatory strategies cannot be provided while attempts are being made to remediate specific skill deficits. For example, providing a child with training in phonological awareness should not preclude using speech synthesis to increase access to text in a particular subject area such as history.

In fact, as suggested by research (Kerchner and Kistenger 1984; Raskind, Higgins, and Herman 1997), using technology for a compensatory purpose also might result in remedial benefits. Of particular interest is our study (Higgins and Raskind 1995) that evaluated the compensatory effectiveness of speech recognition on the writing performance of university students with LD and found that essays written using assistive technology were superior to those generated through handwriting or dictating to a transcriber. Most students continued to use the technology for writing activities (essays, letters, stories) over the next two years following training, and many reported "improved reading abilities" such as enhanced word recognition and comprehension. Participants believed that these improvements were attributable to use of the speech recognition system. These anecdotal reports of improvement by participants were consistent with objective measures such as increases in standardized test scores and course grades, and decreased drop-out rates over the three-year study period (Higgins and Zvi 1995; Raskind and Higgins 1998).

The findings suggested to us the possibility that writing with speech recognition technology also might serve to remediate deficits, and led us to generate hypotheses concerning the mechanism by which speech recognition might affect reading. However, before proceeding with this discussion, it is necessary to provide an overview of how speech recognition systems operate. Speech recognition systems work in conjunction with word processing programs to enable the user to produce written text on a computer through speech. The user dictates into a head-mounted microphone and the speech recognition system (hardware and software) converts the spoken word into electronic text displayed on the computer monitor. "Discrete" speech systems (like the one used in the Higgins and Raskind 1995 study) require a pause of approximately one tenth of a second between words. As words are spoken, they appear on the monitor virtually simultaneously.[1] The system develops a phonetic model of each user's voice that is paired with an English vocabulary file. The identification of words improves over time so that the system becomes more accurate with progressive

[1]Several versions of continuous speech recognition have since become available which do not require one-tenth second pause between words. The text is not presented simultaneously upon speaking, but rather appears on the screen at the end of a sentence or phrase. Detecting speech recognition errors must be done at the end of the phrase or sentence, causing the task to be more like typical proofreading without the word-for-word correspondence of phonemes and graphemes present in discrete speech.

word utterances. Speech recognition programs also utilize statistical information, based on the frequency of the use of word combinations, to predict words.

The first idea to consider in conceptualizing possible links between writing by means of speech recognition and improved reading ability is to recognize that generating accurate text with this technology involves actual reading. As words are spoken into a microphone, the speaker reads/checks the word on the computer monitor to ensure that it is the correct word (the word that was spoken). If it is not, the speaker must choose the correct word from a list of words displayed in a window (choice box), again requiring the user to read. Selecting the correct word requires the user to attend to the specific/unique characteristics (phonemic, graphemic, morphemic) of the word among other, often similar sounding and looking words. Therefore, the mere process of writing with this technology requires users to read/decode words in order to monitor their own written language production. In this regard, perhaps the technology helps to improve reading skills by simply providing an additional opportunity to practice reading. As Lundberg (1995) has stressed, individuals with reading disabilities need greater exposure to print in order to develop adequate word recognition.

Another possibility for explaining how speech recognition technology might enhance reading ability results from the fact that words are presented bimodally: auditorially through speech, and visually through the computer display (virtually simultaneously as they are spoken.) Additionally, a proprioceptive/kinesthetic component is present since the individual has to utilize the appropriate oral mechanisms to speak/articulate words. Although research on the efficacy of multisensory literacy approaches is equivocal (Myers and Hammill 1982), these approaches have a long history in the field as a strategy for improving the academic difficulties of students with LD (Fernald 1943; Gillingham and Stillman 1968; Heckelman 1969).

Furthermore, it is possible that speech recognition technology enhances grapheme-phoneme correspondence. Difficulties with recognizing the relations between the phonological segments in spoken language and their alphabetic counterparts may make reading instruction incomprehensible (Torgesen 1995; Liberman, Shankweiler, and Liberman 1989)[2] and as

[2]See also Ball and Blachman (1991); Berninger et.al. (1998); Bradley and Bryant (1985); Foorman, Francis, Novy, and Liberman (1991); and Swanson and Ramaglia (1992) for evidence of the importance of spelling to recognizing the relation between phonological segments and their alphabetic counterparts.

Torgesen (1995) states, "most children with reading disabilities have great difficulty learning to apply the 'alphabetic principle' to take advantage of grapheme-phoneme regularities in reading unfamiliar words. . . ." (p.77). Perhaps speech recognition technology might improve reading by promoting an awareness of the relation between the phonological segments and alphabetic codes, since the words spoken by the speaker (phonemic segments) are virtually simultaneously translated to their corresponding grapheme representations.

Finally, the notion that reading and spelling can be improved through the use of speech recognition is also consistent with literature dealing with the psychological and motivational aspects of learning. Several authorities in LD (Heshusius 1989, Poplin 1988) contend that the instruction of children with LD is enhanced through interest-driven, and self-paced experiences that can be accomplished independently.[3] Speech recognition technology can provide such a writing experience.

The improvements in reading ability reported by participants in the Higgins and Raskind (1995) study on speech recognition and writing, coupled with the above theoretical and empirical indications, provided the impetus to conduct the present study, a formal investigation of the effects of speech recognition on the reading and spelling performance of students with LD. Both a speech recognition experimental group and a control group were pre- and posttested on academic (dependent) measures of word recognition, reading comprehension, and spelling. In addition, participants in both groups were tested in specific underlying cognitive processes associated with reading, including phonological awareness, orthographic processing, semantic processing, metacognition, and working memory (Swanson and Alexander 1997). It was hoped that potential changes in these cognitive processes might serve to explain concomitant changes in dependent, academic measures. It was predicted that first, the speech recognition group would illustrate significantly higher scores on word recognition, reading comprehension, and spelling at posttesting as compared to the control, and second, these higher scores would show corresponding gains in one or more process measures.

[3]Several strategy-based approaches to spelling instruction for LD students have stressed many of the same principles (Fulk 1997; Graham and Voth 1990; Gerber and Hall 1989).

METHOD

PARTICIPANTS

Thirty-nine students (13 females, 26 males) enrolled at the Frostig School participated in the study. The Frostig School (part of the Frostig Center) is a K–12 private school for children with LD located in Pasadena, California. Students came from predominantly middle- and upper middle-class families. Five children were Hispanic, four African American, one Asian American, and twenty-nine Caucasian. Average age at the beginning of the study was 12.9, and ranged from 9.3 to 17.7.

All participants had been previously identified as LD by their public school district or through diagnostic assessment by Frostig Center staff and allied professionals, and were further screened to meet the criteria agreed upon by the National Joint Committee on Learning Disabilities (1994). Full scale IQ scores ranged from 74 to 137 with a mean of 92.1 and *SD* of 15.0 as measured by *Wechsler Intelligence Scale for Children-III* (Wechsler 1991) or *Wechsler Intelligence Scale for Children-Revised* (Wechsler 1974). Additionally, all students showed deficits of two years or more (below expectation for chronological age) in reading comprehension, phonological analysis, and/or spelling on the *Stanford Diagnostic Reading Inventory-III* (Karlsen, Madden, and Gardner, 1984), with an average discrepancy of 3.3 years in reading comprehension, 4.5 years in phonological analysis, and 3.0 years in spelling.

PROCEDURES

TESTING

Students were pretested on three academic tasks: (1) reading comprehension using the silent reading portion of the *Formal Reading Inventory (FRI)*, Form A (Wiederholt 1986);[4] (2) word recognition using the *Wide Range Achievement Test-3 (WRAT-3)*, Tan Form (Wilkinson 1993);[5] and (3) spelling using the *WRAT-3*. In addition, a battery of tests was administered to assess skills in five cognitive processes identified in previous literature to be related to reading (see Swanson and Alexander [1997] for addi-

[4]Internal consistency coefficients ranged from .92 to .97 across age groups; alternate form reliability was .75 for all of the four alternate forms ($p < .001$).
[5]Item reliability ranged from .98 to .99; alternate form correlations across age groups ranged from .88 to .96.

tional discussion of the development of the individual measures employed).[6] Although the battery is not standardized, the authors were anxious to assess changes in these measures to shed further light on exactly how the technology may have accomplished changes in dependent measures. The battery consisted of the following tasks:

1. *The Phonological Deletion Task*, formulated by Cunningham and Stanovich (1990) and modified by Swanson and Alexander (1997). Children listened to a word, deleted only the first sound, and said the remainder of the word. For example, "spark" should elicit the response "park" (10 items). We included this task because of a long line of research literature in LD that points to phonological awareness as a component directly related to improvements in reading achievement. Given the nature of the task, which requires detecting and especially correcting errors to be described below, we reasoned that it might provide additional practice in distinguishing phonologically similar words, which in turn might assist children in increasing phonological awareness.
2. *The Orthographic Choice Task*, devised by Olson, Kliegl, Davidson, and Flotz (1985) and modified for children by Cunningham and Stanovich (1990). Children were asked to look at cards with two phonologically identical words printed on them, one spelled correctly and one spelled incorrectly. Participants were asked to indicate which was a "real word." For example, for with a card containing "(a) room (b) rume," the correct response was, "a" (25 items). Similarly, given the task of correcting errors, we reasoned that additional practice with distinguishing graphically similar words may have assisted the children in recognizing correctly and incorrectly spelled words, one measure of orthographic processing.
3. *The Semantic Choice Task*, developed by Chabot, Miller, and Juola (1976). Children were shown cards with two words on them. The cards were read aloud and participants were asked if the two words belonged to the same category. For example, one card read, "minute, hour," to

[6]Swanson and Alexander (1997) report reliability coefficients as follows: phonemic deletion, .82; orthographic choice, .77; semantic choice, .78; sentence span (working memory), .76; and metacognitive questionairre, .86.

which the child should respond "same" (30 items). We reasoned that since focus was placed on the content and process of writing (see the Writing Sessions section later in this paper), and since previous research had shown that the development of more mature and complex vocabulary resulted from the use of speech recognition technology (Higgins and Raskind 1995), gains in the semantic organization of vocabulary may have resulted from the experimental condition.

4. *The Metacognitive Questionnaire*, adapted by Swanson and Trahan (1992) from Paris, and Cross and Lipson (1984). Twenty multiple choice questions were read aloud to students. They were asked to circle the answer that best described their attitudes, habits, and strategies concerning reading. For example, one item read,

   A good reader
   a. is also good in all other school subjects (2 points)
   b. may not be good in other subjects such as math (4 points)
   c. has lots of books at home (1 point)
   d. enjoys reading to himself or herself (3 points)

   Each choice within an item had a different value attached to it (calibrated by the originators of the task), as indicated above, so that by adding the values of choices for each item, a total could be obtained for each participant (20 items). This task was included because our group reasoned that exploratory discussions about the writing process and the emphasis on developing a positive attitude toward the writing experience may have altered attitudes and behaviors concerning reading as well as writing.

5. *The Sentence Span Task*, a common test of working memory, developed by Danemann and Carpenter (1980) and adapted for children by Swanson, Cochran, and Ewers (1989). Researchers read a set of sentences aloud, asking participants to memorize the last word of each sentence, in order. After reading the set of sentences, a comprehension question about one of the sentences was asked. The students were to answer the comprehension question, then repeat the last words of each sentence in order. The first set contained two sentences, the second contained three, the third four, and the last contained five sentences (four sets of sentences). The task was in-

cluded because we reasoned that dictation of sentences may provide additional opportunities to develop sentence comprehension, memory, or both.

We were interested to discover whether gains occurred evenly (if at all) over the entire treatment period or whether learning was concentrated at the beginning (or end). During the eighth week of the study, the Blue Form of the *WRAT-3* was administered for word recognition and spelling to all participants. Finally, all three achievement tests, spelling (*WRAT-3*, Tan Form), word recognition, (*WRAT-3*, Tan Form), and reading comprehension (*FRI*, Form B), were readministered at sixteen weeks, along with five of the psychological processing assessments.

APPARATUS

Students were randomly assigned to one IBM® VoiceType (version 3.0) and four DragonDictate® (version 2.5) discrete speech recognition systems. Fourteen participants utilized DragonDictate® and five used VoiceType. The speech recognition programs were installed in Pentium® 133 computers with 16 MB RAM, running Windows™ '95. WordPerfect 6.0 was used as the word processing program. Participants in the control condition utilized 486-66, 8MB computers with WordPerfect 6.0 running Windows™ 3.1.

TRAINING CONDITIONS

Participants were randomly assigned to either the control or the experimental condition (control $n = 20$, experimental $n = 19$). All students received computer instruction, at an individual terminal, for 50 minutes a week for 16 weeks. In both conditions, small group instruction was given and one-on-one assistance was offered when students requested it. Average teacher-student ratios were 2:4 for both conditions (ranges were 2 to 7 students, 1 to 4 teachers).

Control Condition. A computer control group was used to reduce the likelihood that differences in academic and process measures were due to technology use (novelty, attractiveness, and the like) rather than the use of speech recognition itself. The control participants were assigned to a class entitled "keyboarding" which involved such tasks as typing, writing, and using mouse and keyboard manipulations to create art, do research, write compositions, work on math and science projects, play computer games, and operate various instructional programs. Approximately 60 percent of each 50-minute session involved engagement with text (reading, writing, typing, spelling). Approximately 20 minutes of this time was spent writing.

Experimental Condition. These students used speech recognition technology to do writing exercises.

TRAINING FOR THE SPEECH RECOGNITION CONDITION

The first session was spent learning to log on and training their systems to recognize the user's voice. DragonDictate® users read single words aloud from the screen into the system. IBM users, on the other hand, read complete sentences, word-by-word, from the screen into the system. Students were told that if they did not recognize a word from the screen, the researcher or writing facilitator would whisper it for them to repeat into the microphone.

The second session was devoted to mastering techniques of correcting errors in speech recognition. Figure 1 illustrates the DragonDictate® screen as it would appear as a user was dictating the sentence fragment, "This is an example of text being"

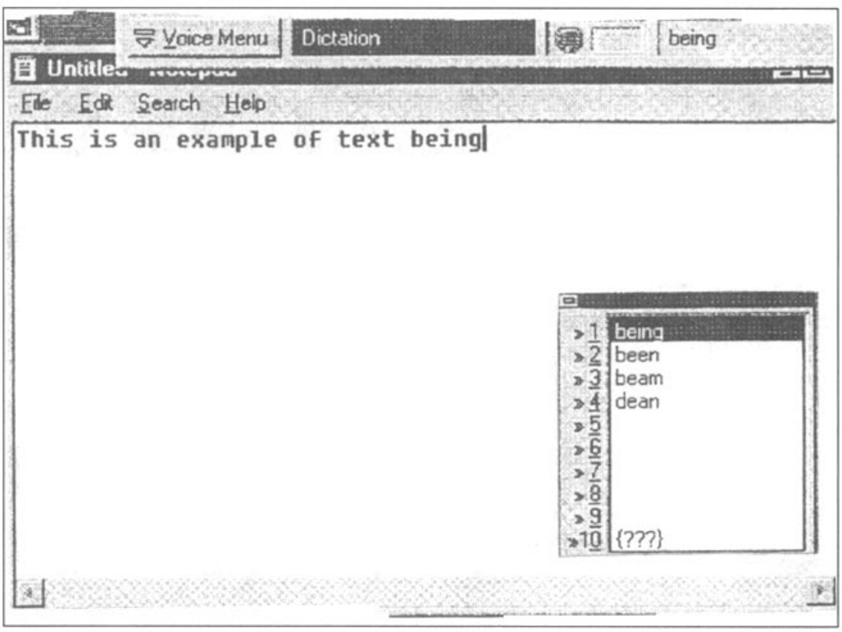

Figure 1. Screen during dictation

The last word dictated, "being," appears in the choice box in the lower right-hand corner of the screen. Notice that the choice box lists several words that are phonetically and orthographically similar to the last word dictated. Students were prompted to watch carefully as each word uttered appeared in text to make sure that it was, in fact, the right word. If a recognition error was made by the system, students were trained in a number of methods to use the choice box to correct the error. One method was to find the correct word among the similar words in the box, and select it by saying, for example, "Choose 4." Another method of selection was to cursor down the list to "4" and hit the enter key. Still another method was to use the mouse to click on "4." Participants were free to choose the correction method they preferred.

Sometimes when a speech recognition error had been made, the correct response was not listed in the correction box. In the example below, the last word dictated, "used," was guessed incorrectly as "acted." Two ways of correcting the recognition error were possible. The first involved spelling the word aloud using the International Alphabet ("alpha, bravo," and so on). Although offered this method, none of the participants ever chose to use it to correct errors. The preferred method of correction involved typing the first letter of the desired word from the keyboard, as in the example in figure 2.

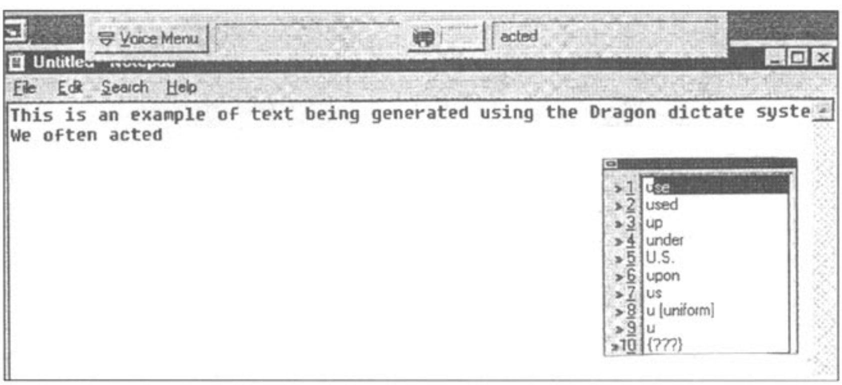

Figure 2. Correction using typing

Typing "u" resulted in the list of words in the correction box in figure 2. Selection 2 is the correct word and could be chosen using cursor keys, the mouse, or the voice command, "Choose 2."[7]

As dictation proficiency increased, the user would sometimes jump ahead of the system's ability to print the words on the screen, so that a recognition error might not be detected until after a few words had already been dictated, as in the example in figure 3. The error, "taxed" for "text," has been passed in dictation.

Using the command "Oops" caused a history of the last six dictated words to appear. Using voice commands or cursor keys, the word to be corrected could be highlighted. The correct selection, in this case number "2," would then be chosen.

WRITING SESSIONS

The above correction procedures were mastered during the first two sessions and the remaining sessions were devoted to using the system for writing. Topics were self-selected in order to max-

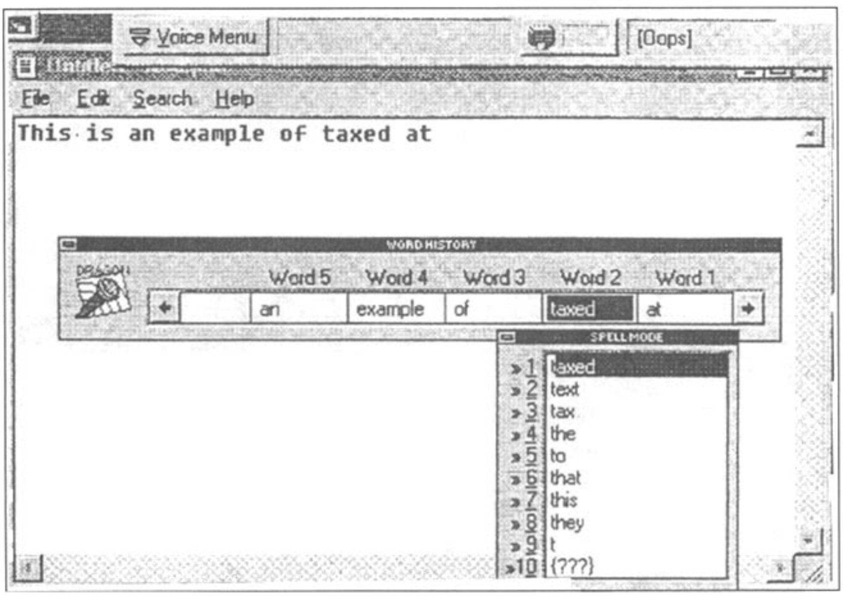

Figure 3. Correction using word history

[7]Correction procedures on the IBM system were similar, except that several corrections were done at once, usually at the end of a dictated sentence.

imize the "meaningfulness" of the text, and to enhance motivation and encourage language production. A portion of the class time in the control condition was also devoted to self-selected activities. Participants could bring in homework and classroom assignments, as long as the assignment involved the dictation of sentences using the systems. Students who did not bring assignments could choose a topic or premise for writing, or were offered a variety of writing motivations designed to stimulate both fiction and nonfiction composition (Schwartz and Armstrong 1989; Senn 1992; Wilmes and Wilmes 1983). See Appendix A for examples of writing motivations from each source.

No formal instruction was given in reading, spelling, or writing. However, writing facilitators did spend five minutes at the beginning of each session to get some students started by helping the student choose a topic or generate the first sentence. A very general approach that encouraged a high volume of language output was adopted. Our reasoning was that if the systems did, in fact, remediate reading and spelling deficits, then the more the children wrote/spoke using the system, the greater the resulting benefit. It should be noted that instructors in the control condition also employed the strategies listed below, as appropriate to that setting. The following recommended strategies were used to facilitate output:

1. Students were, of course, verbally encouraged to write as much as possible.
2. Students were encouraged to discuss the process and content of their writing with facilitators (in most cases a relative strength) rather than the mistakes in the mechanics of their written products (usually a relative weakness).
3. Students were told that the technology was designed to help them utilize their strengths in oral language, and that they should allow the system, as far as possible, to contend with weaknesses such as spelling, punctuation, and the like.
4. One way that positive affective responses to the writing process were encouraged in students was by enlisting only those writing facilitators who were enthusiastic, appreciative, and vocal about the joys and benefits of writing that they themselves had experienced.
5. Writing facilitators were asked to limit heavy editing and criticism of student's work to further ensure that a nonthreatening, noncritical writing environment was provided.

6. Instruction was provided only in the form of information concerning tasks and assignments, the operation of the computer, and the correction of speech recognition errors. Other content was volunteered only when requested by the student.
7. Independent use of the equipment was encouraged in two ways. First, the necessity of correcting recognition errors made by the system was explained to the student, and, although in the beginning he or she was prompted to correct each recognition error as it occurred, facilitators gradually decreased prompts until the student was able to catch most errors himself or herself. Second, students were explicitly and repeatedly reassured that they would be able to, and expected, to use the system without assistance before the project was completed.

As writing sessions progressed, all facilitators were instructed to decrease the amount of assistance extended to the students with regard to preplanning activities and prompting students to catch speech recognition errors. Independent use of the system and percentages of speech recognition errors caught by the participants were monitored regularly during two-minute observation periods. These ranged from 87 percent to 100 percent over the last four writing sessions.

RESULTS

Pretest, midpoint, and posttest scores on the dependent measures of word recognition and spelling, as well as pre- and posttest scores for reading comprehension and for the cognitive processing measures (for both the experimental and control groups) appear in the first two columns of table I. Since alternate forms of the spelling and word recognition tests were administered, absolute scores are reported. The absolute scale combines raw scores from forms A and B of the tests so that they can be compared. To give the reader an idea of the magnitude of change, grade equivalents are also reported, although they were not used in the analysis. Similarly, for reading comprehension, standard scores are also reported in addition to the raw scores upon which the analysis was done to give the reader an estimate of the magnitude of change. Effect sizes are included in the last column of table I.

Table I. Results of repeated measures ANOVA on differences in post-test gains between control and experimental groups.*

Measure	Experimental			Control					
	Mean	*SD*	Grade Level	Mean	*SD*	Grade Level	*F* Value	*p* of *F*	Effect Size
Word Recognition**									
pretest	497.1	13.94	5.2	501.0	14.82	5.9			
midpoint	500.5	15.51	6.0	498.9	14.03	5.6	6.00	.019	
posttest	503.2	13.49	6.5	501.8	13.66	6.2	16.65	.000	1.125
Spelling**									
pretest	494.1	14.25	4.4	496.0	13.62	4.8			
midpoint	498.3	13.36	4.8	498.2	13.08	5.0	4.68	.037	
posttest	500.1	12.36	5.3	498.1	12.71	5.1	10.79	.002	.72
Reading Comprehension									
pretest	9.3	9.90	77.00[2]	16.6	12.45	79.6[2]			
posttest	20.0	13.98	87.05[2]	17.5	13.18	81.6[2]	7.15	.011	.76
Phonological Deletion									
pretest	6.5	3.31		7.9	2.54				
posttest	8.3	2.16		8.3	2.13		4.62	.038	.77
Orthographic Choice									
pretest	23.1	2.90		23.9	2.43				
posttest	24.1	2.50		23.8	2.73		2.12	.154	.35
Semantic Choice									
pretest	27.6	1.54		27.1	2.59				
posttest	28.4	1.80		28.3	2.54		1.14	.294	.54
Metacognitive Choice									
pretest	56.9	10.53		56.4	12.30				
posttest	57.1	9.67		60.4	7.68		1.01	.321	.36
Working Memory									
pretest	.54	.96		.95	.69				
posttest	.68	.75		1.15	.88		.36	.550	.19

*Raw scores are reported with the exception of Word Recognition and Spelling
**Absolute scores are reported

Pretest, midpoint, and posttest gains scores on word recognition and spelling were analyzed separately using MANOVA (Word recognition Wilks' $F = 8.374$, $p = .001$; Spelling Wilks'

($F = 5.931$, $p = .02$). Since significant effects were detected, repeated measures ANOVAs were conducted to determine the direction of effects. A repeated measures ANOVA was also conducted on reading comprehension gains scores (at posttest only) as well. On all ANOVAs, the effects of the covariates of age and entry level performance on the measure have been partitioned out.

Both the control and experimental group made significant progress in word recognition and spelling as measured by posttest scores. Effect sizes were very high for word recognition and high for spelling. However, it should be noted that the experimental group had made significant gains over students in the control group even at midpoint testing, and that these significant differences in gains were even more pronounced at posttest. Similarly, the repeated measures ANOVA revealed that there was also a significant difference in gains in reading comprehension between control and experimental groups over the entire treatment period as measured by the posttest, and it should be noted effect size was high as well.

Pre- and posttest scores on the five cognitive process measures also were analyzed using repeated measures ANOVA. Again, the effects of the covariates of age and entry level performance (beginning score on each measure) have been partitioned out. As can be seen in table I, the use of speech recognition technology appears to have had differential effects on the five cognitive processes measured. Posttest scores for phonological deletion showed significant differences in gains between the groups and a high effect size, whereas the other four measures did not.

Since these findings suggest that changes in phonological processing skill may have occurred as a result of treatment, and further, may have influenced changes in some or all of the outcome measures, additional covariance analyses (using repeated measures ANCOVAs) were employed.[8] Results of the ANCOVAs of phonological gains on the three achievement measures demonstrate that when the covariate (the gains in phonological awareness) is subtracted from the treatment effect, the significance of the differences in gains between the control and experimental conditions disappears. This was shown to be true for all three of the achievement measures of word recognition, spelling, and reading comprehension. F ratios for word

[8]Since little or no difference in gains between groups was shown for the other four measures, ANCOVAs were not conducted.

recognition with and without the covariate were 12.38 ($p < .001$) and 1.56 ($p < .22$), respectively; 6.00 ($p < .019$) and .53 ($p < .47$) for spelling; and 18.0 ($p < .0001$) and .57 ($p < .46$) for reading comprehension.

Since we were interested in determining whether growth was uniform across the treatment periods or whether most change occurred at the beginning (or end) of the treatment period, three data points were measured in word recognition and spelling. Individual differences in the trajectories of change in these dependent measures in response to treatment condition could be calculated using individual growth-curve methodology, which addresses intraindividual change more directly (Bryk and Raudenbush 1987; Foorman et al. 1997; Francis, Fletcher, Stuebing, Davidson, and Thompson 1991; Rogosa, Brandt, and Zimowski 1982; Willet 1988). A two-stage process was employed. First, mean rates of change were determined and estimates made of the extent to which individuals differed across treatment conditions using the SAS Proc Mixed Procedure (SAS Institute 1992). Next, growth-curve parameters for both students in the control and experimental groups were evaluated as to their correlations with the five pretested cognitive processes in order to identify predictors of growth trajectories. Statistics concerning the mean of individual estimates for students in the control and experimental conditions are presented in table II.

As Table II indicates, both control and experimental groups showed a rate of change significantly greater than can be attributed to chance in word recognition, with control participants' slopes indicating 0.69 per unit of time (eight-week intervals), and experimental participants 2.91 per unit, four times the rate of controls. In spelling, students in the control

Table II. Mean individual growth curve estimates for word recognition and spelling.

Measure	Estimate	S. E.	T*	p
Word Recognition				
Control	0.69	0.34	2.03	.0440
Experimental	2.91	0.35	8.31	.0001
Spelling				
Control	1.08	0.48	2.23	.0290
Experimental	2.89	0.50	5.84	.0001

*Test statistic for rejection of null hypothesis estimate > 0 and experimental conditions showed change significantly greater than chance, with experimental participants demonstrating almost three times the growth rate.

Although pretest scores on dependent measures were controlled in the ANOVA, many researchers have noted the relation of entering performance on the various cognitive measures on subsequent growth in reading as well (Foorman, Francis, Novy, and Liberman 1991; Swanson and Alexander 1997). The correlations of pretests on cognitive process measures, with individual growth-curve estimates of combined experimental and control group participants, are presented in table III.[9]

All correlations proved significant, with the exception of working memory and spelling, supporting the hypothesis that all measures are good predictors of individual change trajectories in word recognition, and that all but working memory are good predictors of individual change rates for spelling. It also should be noted that most of the significant coefficients are similar to one another in magnitude, indicating that all are somewhat equal in their ability to predict growth.

DISCUSSION

Results of the growth curve analysis and the analyses of variance strongly indicate that the intervention "worked", that is, improved word recognition and spelling in students diagnosed with LD, and the analysis of variance indicates that the positive

TABLE III. Correlations of pretest scores on cognitive measures with individual growth-curve estimate slopes (Includes both experimental and control participants, $n = 39$).

Pretest Measure	Word Recognition Growth-Curve Estimate	Spelling Growth-Curve Estimate
Phonological Deletion	.61	.56
Orthographic Choice	.58	.62
Semantic Choice	.67	.56
Metacognitive Choice	.62	.57
Working Memory	.32	.18

$p < .05$

[9]Groups were collapsed due to the small sample size as well as the fact that both treatments showed change greater than chance.

effects also extended or transferred to reading comprehension. The study supports previous research that indicated remedial effects resulted from the use of speech recognition technology with postsecondary students. Our previous three-year longitudinal follow up of postsecondary users who employed the technology assistively showed long-term gains in reading, as measured by passage rates on standarized tests, in overall academic achievement as evidenced by better grades in courses requiring extensive reading, and in improved graduation, retention, and drop-out rates (Higgins and Zvi 1995; Raskind and Higgins 1998).

The findings are also concordant with those of other researchers who have utilized assistive computer technologies to enhance reading performance. Elkind, Black, and Murray (1996) and Elkind, Cohen, and Murray (1992, 1993), for example, showed improved reading speed and comprehension using speech synthesis/optical character recognition systems, although those studies did not find a remedial effect for reading, a transfer to written text when not using the technology. The present study compares favorably as well, however, with previous research on computer interventions that *did* find a remedial effect for reading (and in some cases spelling) (Foster, Erickson, Foster, Brinkman, and Torgesen 1994; Olson and Wise 1992; Torgesen 1993; Torgesen, Waters, Cohen, and Torgesen 1988), even though the speech recognition program used in the current study was not designed specifically to remediate reading difficulties. The referenced computer interventions in this study are phonologically based so that research on them has frequently measured phonological awareness, and has confirmed that improvement along this measure can be accomplished by explicit phonological instruction/practice. Other phonologically based remedial interventions that do *not* involve the use of a computer have demonstrated similar findings for reading (Alexander, Anderson, Heilman, Voeller, and Torgesen 1991; Foorman, Francis, Novy, and Liberman 1991; Lindamood and Lindamood 1979, 1984; Lie 1991; Olofsson and Lundberg 1983; Torgesen, Morgan, and Davis 1992), and spelling (Ball and Blachman 1991; Bradley and Bryant 1985; Foorman, Francis, Novy, and Liberman 1991).

Although the research reported here replicates and confirms the work of others in the field, in many respects, as indicated above, certain findings are unique to the study and deserve mention. Many previous researchers have suggested that phonological awareness is linked to reading acquisition (Felton and

Wood 1989; Juel, Griffith, and Gough 1986; Mann 1993; Perfetti, Beck, Bell, and Hughes 1987; Stanovich, Cunningham, and Cramer 1984; Wagner, Torgesen, and Rashotte 1994). Several studies also have demonstrated that children with LD can show increases in various phonological tasks as a result of explicit training in phoneme awareness (Alexander, Anderson, Heilman, Voeller, and Torgesen 1991; Ball and Blachman 1991; Fox and Routh 1984; Lie 1991; Torgesen, Morgan, and Davis 1992). A few have provided evidence, using growth curve analysis, that beginning scores in various phonological tasks can predict subsequent success of phonological training (Foorman et al. 1997; Torgesen and Davis 1996).[10] A small number of researchers have demonstrated growth in word reading in older elementary students with reading disabilities (Lovett and Steinbach 1997; Oakland, Black, Stanford, Nussbaum, and Balise 1998), and one study (Guyer and Sabatino 1989) has shown success using a "multisensory, alphabetic phonetic" approach with college students. The present research employed the growth curve analysis, and analyses of variance and covariance to extend the above findings by: (1) demonstrating directly the relation, not only between beginning score in phonological awareness (aptitude) and outcome measures (word recognition, reading comprehension and spelling) but also between growth in phonological awareness and growth in outcome measures; (2) utilizing a broad range of ages and grade levels to further demonstrate that older, disabled readers can also benefit from reading intervention; (3) pinning down even further the relation of phonological processing to reading comprehension, typically either not measured or not elaborated extensively in measurement instruments targeting the very young children who are the subjects of early acquisition studies; and (4) enhancing our understanding of spelling outcomes by demonstrating that phonological growth was strongly associated with spelling growth.

HOW DID SPEECH RECOGNITION IMPROVE PHONOLOGICAL AWARENESS?

As stated above, this study showed that gains in reading and spelling were strongly associated with growth in phonological awareness. However, the specific mechanisms that led to increased phonological awareness are not known. Although this

[10]Swanson (1992) has suggested, however, that a more general factor composed of measures of working memory outperforms single congnitive processing components as predictors.

study was not designed to determine how the use of speech recognition improved phonological awareness, there are several possibilities.

First, it is conceivable that speech recognition technology, through the process of converting the spoken word to electronic text, provided specific practice in acquiring rule-based phoneme/grapheme correspondences. Lundberg (1995) stressed that many children with reading disabilities have difficulty extracting phonemic units from spoken language and mapping them "on to the grapheme units of written language" (p. 91). Furthermore, Lundberg (1978, 1995) has emphasized that when words are spoken, there is little conscious awareness as to the phonological segments used by the speaker, in contrast to reading (decoding) text (Lundberg 1984; Lundberg, Frost, and Petersen 1988), which requires specific awareness of phonemic segments. Similarly, Share (1995) has stressed that practice in phonological recoding (print-to-sound translation) functions as a self-teaching mechanism that leads to skilled word recognition. It is possible that speech recognition technology promoted an awareness of the relation between the phonological segments and alphabetic codes (and also functioned as a self-teaching mechanism) since the words spoken (phonemic segments) are simultaneously translated to their corresponding grapheme representations.

Second, correcting speech recognition errors by use of the choice box may have provided necessary practice in phonological awareness. As previously discussed, if the word displayed on the computer screen was incorrect (different from the one spoken by the user), the user needed to refer to the choice box and select the correct word from a list of similar sounding and looking words. In so doing, the user may have increased attention to specific internal characteristics, including phonemic units/phonological segments.

Third, perhaps the bimodal presentation of words—hearing them through the speaker's own voice, and seeing them simultaneously displayed on the computer screen—served to improve phonological awareness. This idea is consistent with research by Olson and Wise (1992) who reported that reading disabled children who had read stories on a computer with synthetic speech support made significant gains in phonological decoding and word recognition as compared to a control group who received reading instruction without computerized speech support. In addition to the auditory and visual components, the use of a speech recognition system also involves a proprioceptive/kinesthetic component since the individual has to utilize the appropriate oral mechanisms to speak/articulate words. Along these lines, Oakland, Black, Stanford, Nussbaum, and Balise (1998) also have shown such multisensory training to be effective in enhancing phonological abilities.

Finally, speech recognition may have provided a meaningful and motivating context for interacting with text and increased opportunities for phonological exploration and play, such as rhyming, alliteration, and other formal devices. Lundberg (1995) has emphasized that reading is best developed . . . "by reading material that has personal significance and meaning to the reader" (p.92). Regarding phonological awareness, he states: "What children at risk for dyslexia may need is specialized practice with meaningful materials that allow them to abstract phonological segmentation skills, which can then be applied to learning grapheme-phoneme correspondence" (p. 92).

In accordance with other studies (Ball and Blachman 1991; Blachman, Ball, Black, and Tangel 1994, Wagner and Torgesen 1987), the present research suggests a strong association between improved phonological skills and enhanced reading abilities. However, unlike these studies, the present intervention did not provide explicit phonological training. In fact, it did not include any formal instruction in either reading or writing, aside from perhaps modeling the preplanning activities of choosing a topic and jotting down brief notes about major points. Again, students in the experimental group simply wrote (by means of speech recognition) anything they felt inclined to write; the writing activity was carried out independently and in a nonstructured, interest-driven context. The only instruction given to the participants was regarding the operation of the speech recognition system. Despite the fact that no explicit phonological training was given, students in the experimental group showed significant gains over the control group in phonological awareness (phonological deletion). Although it is difficult to determine the precise mechanisms that led to these gains, evidently the interaction between the user and the speech recognition system provided implicit phonological instruction/training embedded in an authentic and realistic academic context. This finding contradicts the suggestion by other researchers (Lovett and Steinbach 1997; Wagner, Torgesen, and Rashotte 1994) that it is necessary to provide systematic, intense, isolated, and explicit phonological training to enhance the phonological skills necessary for proficient reading in this population.

In support of our view, a few researchers such as Olson and Wise (1992) have speculated that it is possible for the correspondence of subword letter patterns and their speech sounds to be implicitly learned from whole-word feedback without attention to subword segments (p. 178). Similarly, Leong (1991), citing work by Perfetti, Beck, Bell, and Hughes (1987) and Ehri (1984), suggests that reading by itself, by means of exposure to orthographic representations, can lead to enhanced phonological knowledge.

Perhaps it could be argued that what we have termed implicit instruction is in actuality explicit. While using speech recognition technology, participants may have been forced to attend to, or make explicit, the phonological characteristics of words in both the process of monitoring the match between the words spoken and its grapheme representation, and in the process of correcting words from the list of similar sounding and looking words. However, the nonstructured nature of writing activities through speech recognition appears, in itself, to be a far cry from what might be considered explicit and systematic instruction in phonological awareness.

CONCLUSIONS/IMPLICATIONS

Over the past few years, in an attempt to provide assistive technology to persons with LD, our research group has consciously developed a line of research that has stressed using computers to accomplish authentic academic tasks, which, in turn, serve real educational, social, and recreational goals for persons with LD (Higgins and Raskind 1995, Raskind and Higgins 1995b, 1998). We wish to offer the suggestion that task-analyzing these authentic experiences mechanistically, or removing them too far from the social, educational, and recreational settings in which they occur, while appropriate for some purposes, could quite possibly invite the loss of transfer back to those very targeted authentic tasks. We believe that we have been able to demonstrate transfer to reading comprehension because the focus on and practice with phonological segments has occurred as a natural outcome of the desire to generate comprehensible language in the context of real sentences and paragraphs that have inherent personal meaning for the students. Our group cautions that attempts to replicate the positive results obtained in training that deviates too far from the reading and speaking/writing experience as it occurs in the natural settings in which students interact, may not succeed. Of course, only empirical research can clarify this issue.

In a related issue, we wish to stress again that instruction and adult supervision in learning to operate the technology during the first few sessions is critical to the successful use of the equipment for writing purposes, and that intermittent monitoring will be required to ensure that word recognition errors continue to be corrected by the user. If this is not done, voice files will become filled with incorrect linkages of spoken words with text and the system will no longer recognize the user's utterances accurately. Additionally, we found it necessary to have an abundant supply of stimulating activities at hand to ensure that participants were motivated to continue using the system (see examples in Appendix A). Finally, it was also important to spend three to five minutes, at the beginning of the early sessions with each student individually, to help in getting started; choosing a topic, listing two or more details or elaborations on the topic, and perhaps rehearsing the first sentence to be dictated. This is an especially important point when considering that some students did not have a positive emotional reaction to the systems and, in fact, several found the technology tedious, demanding, and frustrating to operate. Without this scaffolding activity, it is doubtful that students, even the most mature, would have continued to use the system effectively. We have conducted other research (Raskind, Higgins, Slaff, and Shaw, 1998) that further confirms that speech recognition technology is particularly vulnerable to underuse or misuse when inadequate support is offered.

In this regard, the argument could be made that similar results may have been obtainable with an intervention that required 50 additional minutes of writing, but that used pencil and paper and/or a word processor. We respond first that all students, both control and experimental participants, already received four hours of writing per week in class (separate from time spent in control and experimental conditions). In addition, part of the control students' time in the keyboarding class was spent writing as well (approximately 20 minutes), and 60 percent of their computer time involved text-related activities. In fact, total time writing for the control group was 4 hours, 20 minutes per week, whereas the experimental group received 4 hours, 50 minutes per week, a difference of only 30 minutes. Although possible, it seems unlikely that this 30 minute difference in writing activities per week (6 minutes more per day) accounted for such significantly greater gains in reading and spelling.

Another case could be made that writing on a computer (word processing) *without* speech recognition would also yield gains in reading and spelling. However, the extensive body of research on the IBM *Writing to Read* software program, designed to support such a notion, yielded equivocal findings (Jones 1993; Singh 1991). We believe that perhaps these results are equivocal because writing with a word processor—or pencil and paper—does not involve three of the components present in the speech recognition experience that have already been enumerated to be associated with reading improvement: (1) simultaneous, multi-sensory presentation of text (visually) and its auditory counterpart; (2) the necessity for monitoring the match between the visual output and its (intended) phonological representation; and (3) practice in reading *correctly spelled* text.

Additionally, we fully acknowledge that there is considerable research to support improvements in reading as a result of spelling and writing interventions with students with learning disabilities (see Ehri 1992 for a current review of such literature), as they have similarly acknowledged that a variety of reading and language-related interventions are effective. The researchers obviously cannot claim to have found the best method of teaching reading to children; only that the assistive use of speech recognition to generate written text can have a remedial effect.

THE RELATION BETWEEN REMEDIAL AND ASSISTIVE TECHNOLOGY

As previously discussed, Raskind and Scott (1993), emphasized the need to have a clear understanding of the differences between assistive and remedial technologies in order to ensure the attainment of specified educational goals. Interestingly, this study illustrated that speech recognition, an assistive writing technology, actually served to remediate/improve reading and spelling abilities. Although it is critical for an educator to know the primary purpose in providing an assistive technology, and to identify specific learning goals and the technology necessary to reach them, it is also important to understand that it is possible to accomplish both purposes with one technology. Some educators have expressed concerns that technologies designed to compensate for LD merely provide crutches for individuals with LD and do not serve to improve basic skill deficits, tending, rather, to make people dependent rather than independent. However, even without arguing the validity of such a notion from philosophical, theoretical, or research standpoints, we can now allay such concerns by adding the current research to the list of other studies (Kerchner and Kistenger 1984; Raskind, Higgins, and

Herman 1997) suggest that assistive technologies may have remedial value. This is not to say that all technologies will have remedial value. However, in some instances, the educator may be lucky enough to have access to a technology that provides the best of both worlds.

APPENDIX A
EXAMPLES OF WRITING MOTIVATIONS

"Many public libraries set aside one week each year for encouraging people to return overdue books. Write a humorous story about a library book that is ten years overdue. Describe the unusual circumstances that have prevented its return for so long a time."

—Schwartz and Armstrong

"Trees stay in one place their entire lives. What would it be like to be stuck in one place all your life like a tree? What would you see, hear, feel?

—Wilmes and Wilmes

"List the reasons why you would like to be covered with fur like an animal instead of wearing clothes."

—Senn

ACKNOWLEDGMENTS

The authors would like to express their gratitude and sincere appreciation to the Mufasa Trust for their generous support of this research.

A special thanks is extended to Dr. Lee Swanson of the University of California, Riverside, for his guidance in the selection of testing materials and for his analyses of the data as to growth curve parameters.

A thank you also needs to be given to Tobey Shaw, Dr. Ken Herman, Bob Goldhamer, Deborah Hori, Barbara Lundsten, Reid Schenck, Dr. Patty Finn, and Nancy Emolo of the Frostig Center for their assistance with testing and technology training.

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