Using talking computers to remediate reading and spelling disabilities: The critical role of the print-to-sound unit

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Talking computers employing computer-generated speech feedback have been used to remediate the literacy skills of dyslexic readers. A computer program is described that employs DECtalk, a high-level speech synthesizer, to narrate instruction involving intensive training in identifying whole words or in identifying and blending word segments corresponding to onsets, rimes, and phonemes. Procedures for developing individualized instruction are described as well as for constructing and editing the speech and graphics features of the program. Neurologically impaired dyslexic children trained with this program achieved greater acquisition and transfer of word recognition skill when their training involved segmented rather than whole word feedback.

A substantial amount of research on teaching literacy with talking computers has employed high-level speech synthesizers (e.g., Barron et al., 1992; Farmer, Klein, & Bryson, 1992; Lovett, Barron, Forbes, Cuksts, & Steinbach, 1994; Olofsson, 1992; Olson & Wise, 1992). These systems allow considerable flexibility, because they operate by transforming strings of ASCII characters into high-quality spoken output that is adjusted for a number of phonological and prosodic features of speech.

Olson, Wise, and their colleagues have pioneered the development of computer-based reading systems that use DECtalk (e.g., Olson, Foltz, & Wise, 1986), a text-to-speech conversion system based on Klatt's (1980, 1987)

analysis-by-synthesis procedures and developed by the Digital Equipment Corporation (Bruckert, Minow, & Tetschner, 1983; Vitale, 1993). DECtalk produces speech output that is very close to the intelligibility of natural speech (see, e.g., Greene, Logan, & Pisoni, 1986; Mineo & Cavalier, 1990), and it can be understood by children, including those with reading disabilities (e.g., Leong, 1992; Wise et al., 1989).

Olson and Wise (1992) hypothesized that developmentally dyslexic children might benefit from instruction that employs DECtalk to provide on-line, spoken feedback about the segmental structure of printed words. Children in their training experiments read a passage of text displayed on a computer monitor and then indicated the words that they did not know with either a mouse or a light pen. An unknown word was highlighted in reverse video and then immediately spoken by DECtalk in a whole word condition, whereas the orthographic units corresponding to syllabic or subsyllabic segments (onsets, rimes, and phonemes) were highlighted and then spoken by DECtalk in segmentation conditions. Children responded to the DECtalk feedback by either repeating the whole word (whole word condition) or blending the segments into a whole word pronunciation (segmentation conditions).

Following 6–8 h of computer instruction time per subject, Olson and Wise (1992) found that whole word, syllable, and onset rime feedback were equally effective in producing gains in word and nonword recognition in

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comparison with the performance of a control group that did not receive computer training. Grapheme-phoneme segmentation, however, produced the smallest gains in performance in comparison with the whole word and segmentation conditions in a shorter term (2-day) study (Wise, 1992).

We describe a computer speech program that employs DECtalk to teach word recognition and spelling skills to children with severe reading disabilities. The organization and content of our instruction is based on research by Lovett and her colleagues on the effectiveness of different instructional procedures for remediating word identification and spelling deficits in dyslexic children (e.g., Lovett, Ransby, & Barron, 1988; Lovett, Ransby, Hardwick, Johns, & Donaldson, 1989; Lovett, Warren-Chaplin, Ransby, & Borden, 1990). We also use DECtalk's capability for segmenting words. But our approach differs from that of Olson and Wise (1992) in that it involves intensive and carefully monitored instruction on the orthographic and corresponding phonological subunits of individual words that the reader does not know, rather than just providing feedback about their segmental structure during the reading of a passage.

Database Organization

The computer program database of 745 words, taken from Lovett et al. (1990), consisted of regular words that conformed to English spelling-to-sound correspondence patterns (e.g., *made*) and exception words (e.g., *have*) that did not. The whole word pronunciation of each regular and exception word was represented in the database in ASCII characters along with two additional pronunciations of each of the regular words involving different sub-syllabic segmentations. The first consisted of grapheme-to-phoneme correspondence units within each syllable (e.g., *stop: s = /s/, t = /t/, o = /a/, p = /p/*), and the second consisted of orthographic and phonological units corresponding to onsets and rimes (*stop: st = /st/, op = /ap/*). The latter provided a level of segmentation intermediate between grapheme-phoneme correspondences and whole words (Treiman, 1992).

The spelling of each regular and exception word was represented as a string of letter names recited in serial order. Finally, the meaning of each word was conveyed through its appearance in three context sentences: two in the reading component of the program and one in the spelling component for a total of 2,235 sentences.

The 745 words in the database were divided into three lists of regular words and two lists of exception words that were equivalent in number of letters, number of one-, two-, and three-syllable words, orthographic structure (single letter and bigram frequency), part of speech, and frequency of occurrence in printed English. All 745 words were presented during pretesting, to determine which words each child could read and spell accurately before training.

One of the regular word lists and one of the exception word lists were arbitrarily designated as "taught to" (TT)

lists, and the words that the children were taught during the lessons were drawn from them. The remaining exception word list and one of the remaining regular word lists were designated as "not taught to" (NTT) lists, and they were used to assess transfer-of-training effects. The fifth list, consisting of regular words, was used for subjects who exhausted all of the to-be-learned words in their TT training lists during the lessons.

Hardware and Software

The computer system comprised an IBM 286 clone and two monitors. The student's monitor (VGA color) displayed the words and word segments used during instruction in graphics mode. The instructor's monitor (monochrome) used text mode and displayed information for controlling the flow of events during the lessons and the dialogue spoken by the DECtalk speech synthesizer (Model DTC01) during the instruction. The instructor used a mouse to initiate DECtalk dialogue and other functions displayed on the instructor's monitor and to initiate the speech sounds associated with the words and word segments when cursor control was transferred to the student's monitor.

The computer software was written in Turbo Pascal 5.0 (DOS) and, from the perspective of the instructor, involved a series of windows that could be opened at various points during the course of instruction. The windows contained text statements organized in a menu format corresponding to the appropriate DECtalk dialogue for a particular instructional segment, and they provided access to information in the database concerning the words and sentences used in the instruction (e.g., whole word and segmented pronunciation, letter-by-letter spelling, context sentences). The windows also contained information used for accessing graphically based "cards" consisting of sound symbol and pronunciation rule displays presented on the student's monitor during the teaching of regular words in the letter sound and onset rime segmentation conditions. Similar "cards" were used in teaching all of the words during the spelling section of the lessons.

Instructional Dialogues for Teaching Word Recognition Skills at Three Levels of Segmentation

Overview. Instructional principles common to all of the literacy training programs included (1) individualized training content for each child based on what they did and did not know at pretest; (2) an emphasis on rehearsal and review of known words in order to consolidate existing reading vocabulary; (3) a controlled rate of introduction for new material; and (4) systematic consolidation and review of newly learned words to achieve fast and accurate word identification and spelling.

A lesson had three parts. Part 1 involved review and consolidation of existing word knowledge. A review list of 10 regular and 10 exception words taken from the student's two TT word lists was displayed on the instructor's

monitor. These were words that the student could read correctly at pretest or had been taught successfully in previous lessons and, as with all of the lists, were ordered from high to low word frequency. The 20 review words were then displayed one at a time on the student's monitor, and the student attempted to read each word aloud. Incorrectly read items were designated as words that the student did not know reliably and, therefore, were members of the pool of words (again, ordered in frequency) that would be taught in subsequent lessons. Others in the to-be-taught pool included words that were incorrect in previous training sessions, as well as words that the student did not know during pretest and had not yet learned.

In Part 2 of the lesson, three new (i.e., not known) regular words and three new exception words were chosen for instruction. All of the exception words were taught using a "sight" word or whole word recognition procedure. Regular words, in contrast, were taught using whole word, letter sound segmentation, or onset rime segmentation procedures, depending on the instructional condition to which the student had been randomly assigned. Part 3 of the lesson involved 10 regular and 10 exception words from the two TT lists that the student could read correctly at pretest or had mastered in previous lessons. These words were displayed on the student's monitor, and the task was to read them three times as

rapidly and accurately as possible (both accuracy and latency were recorded by the computer); any incorrectly read items were designated within the database as not known. Consolidation and automaticity in word identification were the goals of this part of the instruction, although specific response time criteria were not employed.

Whole word instruction dialogue. A flow diagram of the sequence of events involved in the whole word instructional dialogue is presented in Figure 1. Following the review session described in Part 1 of the lesson above (Window A), Part 2 of the lesson began by opening Window B and selecting three new regular words or three new exception words for instruction. The three selected words (e.g., the regular words *make*, *did*, and *after*) were displayed in the menu for Window C on the instructor's monitor and on the student's monitor. Clicking the mouse on the first word *make*, for example, opened Window D on the instructor's monitor and highlighted that word on the student's monitor by changing its color. The menu for Window D consisted of a series of text statements corresponding to DEctalk's contribution to the instructional dialogue.

Clicking the mouse on the text statement "This word is *" resulted in DEctalk's saying "This word is make," and clicking on "context sentence" resulted in DEctalk's saying the two context sentences associated with *make* within 200 msec (e.g., "What flower shall I make" and

Figure 1. Flow diagram of the sequence of events involved in the whole word instruction dialogue.

"This is the card I would like to make"). The instructor then manually pointed to *make* on the student's monitor and clicked "What word?" in the Window D menu. DECTalk said "What word?" and the student responded by attempting to read *make* aloud. Oral feedback on the student's pronunciation accuracy was provided by the instructor. Instruction for the second and third words (e.g., *did*, *after*) involved returning to Window C and repeating the previous sequence.

Consolidating the student's ability to identify the newly learned words involved the "Point to..." and "What word?" menu items in Window B and opening Windows E and F. For example, DECTalk said "Point to make" when the first word in Window E was clicked; the student responded by pointing manually to *make* on his/her monitor. Similarly, DECTalk said "What word" when the first word in Window F was clicked; the student responded by trying to read *make* aloud. The instructor provided feedback on response accuracy in the "Point to..." and "What word?" exercises. Both exercises were repeated with all three words and in different orders until the student was fast and accurate in manual pointing and reading aloud.

The whole word instructional sequence was applied to the three exception words (e.g., *foot*, *said*, *could*) in the remainder of Part 2 of the lesson. In Part 3, the Window B menu was used to open Window G, where two lists of 10 words were displayed for consolidating students' speed and accuracy in reading regular and exception words that they already knew from their TT list.

Letter sound and onset rime instruction dialogue.

A flow diagram for the letter sound instruction dialogue is presented in Figure 2. Following the initial review session with Window A and whole word instruction of the three new exception words (Windows B–F), the Window B menu was used to open Window G, which contained three new regular words to be taught by letter sound instruction. Clicking on the first word (e.g., *trees*) opened Window H, and clicking "intro word" in the menu placed the word *trees* on the student's monitor and opened Window I. Clicking on "This is the word *," the two context sentences, and "Say the word?" allowed DECTalk to introduce the word *trees*. Following the student's response, DECTalk said "Let's look at trees" and then "We are going to look at the sounds in trees." Window H was then reopened in order to transfer cursor control to the student's monitor and display the sound symbol card for *trees*.

A sound symbol card consisted of the target word at the top with the letters or letter clusters (i.e., graphemes) corresponding to the individual sounds (i.e., phonemes) in the word arranged below. For the word *trees*, the letter *t* was displayed along with the letters *r*, *ee*, and *s*, as well as some foil items such as *p*, *d*, and *ay*. Affixes (e.g., *tion*, *ing*) and *r*-controlled vowels (e.g., *ar*, *er*) were presented as units in these displays. Clicking on *trees* or on a letter or letter cluster (e.g., *ee*) highlighted that item on the student's monitor by surrounding it with a box and opened Window J on the instructor's monitor. DECTalk

was prompted to say "Here is the sound /i/" (the phoneme /i/ corresponds to the letter cluster *ee*) followed by the question "What sound?" The student responded by trying to say /i/ aloud, DECTalk repeated the sound /i/, and the instructor provided oral feedback about the student's accuracy. This dialogue was repeated until the student could fluently identify all of the letter sound and letter cluster sound correspondences on the sound symbol card.

Following letter sound consolidation, the sound symbol card was removed from the student's monitor and Window H was reopened followed by Window K. The word *trees* was displayed on the student's monitor, and DECTalk said, "Now we are going to sound the word out" and "Get ready." The student's first attempt to blend or synthesize *trees* was followed by DECTalk's saying *trees* segmented into individual phonemes (i.e., /t/, /r/, /i/, /z/). DECTalk then said "What word? Say it fast." At this point, the instructor manually pointed to the orthographic units in *trees* (lingering somewhat longer on the vowels) while the student again attempted to blend or synthesize the pronunciation. DECTalk uttered the whole word *trees* as feedback, and the instructor provided feedback on response accuracy. These instructional steps were repeated until the student could blend the word accurately and consistently.

Window H was also used to display a list of words that rhymed with the instructed word on the student's monitor and to reopen Window J on the instructor's monitor. DECTalk said "These words rhyme with trees. What words?" The student responded by attempting to read the list of rhyming words (e.g., *bees*, *knees*, *sees*). The instructor provided feedback on response accuracy, and DECTalk was used to provide feedback on the whole list of rhyming words and on individual rhyming words that were read incorrectly.

Where appropriate, the menu in Window H was used to retrieve a pronunciation rule card which consisted of a printed statement on the student's monitor of a rule exemplified in the instructed word. The instructor and the student read the pronunciation rule card, the student memorized the rule, and then he/she attempted to apply it to some new words displayed on the card. This sequence of instructional steps, employing Windows G–K, was repeated in teaching the remaining two regular words, and then Window M was used to conduct the accuracy and speed consolidation drills for Part 3 of the lesson.

Multisyllabic words were displayed on the sound symbol card as whole words and also divided into syllables (displayed in different colors) with the individual letter sound units arrayed below each syllable. A multisyllabic word was taught one syllable at a time, with DECTalk prefacing the instructional session (from the menu in Window J) by saying, for example, "The word desperation has more than one part." "The first part is des." "We are going to look at the sounds in des." The letter and letter cluster sound units associated with the first syllable

Figure 2. Flow diagram of the sequence of events involved in the letter sound and onset rime instruction dialogues.

(e.g., *d*, *e*, *s*) were learned fluently following the letter sound instructional sequence described above before attempting to learn the units making up the subsequent syllables. Finally, the student attempted to blend the whole word and then heard DECTalk say the whole word divided into phonemes (i.e., /d/, /ɛ/, /s/, /p/, /ər/, /e/, /ʃən/) when the syllable segmented version of the word on the sound card (i.e., *des + per + a + tion*) was clicked. This was followed by the student's again attempting to blend

the word, whole word feedback from DECTalk, and feedback on response accuracy by the instructor.

The instructional sequence and windows for the onset rime condition were the same as for the letter sound condition, except that individual syllables were divided into larger units corresponding to onsets and rimes rather than into phonemes (see Figure 2). Onsets and rimes were employed as units in the segmented pronunciation of each syllable and as units of instruction in the sound symbol cards.

Spelling Instruction Dialogue

The initial review (Part 1) and final consolidation (Part 3) of a lesson in spelling instruction were similar to those for reading except that the students were required to write out the words during both parts of the lesson. This exercise included writing one word as often as possible in 1 min during Part 3. The spelling instruction employed in Part 2 of the lesson was the same for both the regular and the exception words. Window O was opened, and one of three regular or exception words was selected for instruction from the menu followed by the opening of Window P. Clicking the mouse on "Spell the word" and a context sentence provided the DECTalk dialogue for introducing that word. The student wrote out the word and then checked it against the correct spelling, which was displayed on a spelling card on the student's monitor. DECTalk then spelled out the word letter name-by-letter name. The instructor also spelled out the word rhythmically and asked the student to spell the word orally four times with the spelling card present. The spelling card was removed from the screen, and the student was instructed to spell the word orally an additional three times and to write it out once. The spelling card was presented again so that the student could check the spelling; then it was removed, and the student was requested to write out the word three times. This instructional sequence was repeated for the remaining words.

Constructing and Editing Sound Symbol Cards

The sound symbol cards used in teaching the regular words in the letter sound and onset rime conditions were constructed with a program that allowed the user to type in the target word, the orthographic units corresponding to its phonological segments (e.g., syllables, onsets, rimes, phonemes, *r*-controlled vowels, and affixes), and the words with which it rhymed. Colors could also be selected for the individual units and the units positioned on the letter sound card with the use of a mouse.

The program also contained a phonetic editor for editing and testing the pronunciation of the phonological segments. The phonetic editor consisted of a matrix of the ASCII characters for each of the 17 vowel and 24 consonant phonemes used by DECTalk as well as for other functions, including primary and secondary stress; word, syllable, and morpheme boundary markers; and intervals of silence.

It was necessary to represent most individual consonants with the target consonant (e.g., /t/) and a neutral vowel (e.g., /ə/), because some of DECTalk's synthetically generated consonants (stops, and some fricatives and affricates) did not sound like letter sound names (e.g., "tuh") unless they had a following neutral vowel (e.g., /tə/). The phonetic editor also permitted one to manipulate the duration of a phoneme or a silent interval by using a mouse-controlled horizontal bar graph. This feature was useful for increasing the intelligibility of individual phonological segments in the letter sound and onset rime segmented words in the database.

DECTalk pronounced single words as they would occur in connected discourse and, therefore, took into account linguistic phenomena such as vowel reduction, morphophonemic alternation, consonant cluster simplification, and subphonemic attenuation. These natural speech modifications occasionally reduced the intelligibility of single words when DECTalk pronounced them in isolation, and in these instances, the phonetic editor was used to make changes in the words (e.g., lengthening the duration of the vowel) that allowed them to be perceived more easily. Finally, the phonetic editor allowed phonological segments to be played back, accompanied by DECTalk's ASCII representation of the segment on the monitor—a representation that could also be edited.

Remediating the Literacy Skills of Dyslexic Children

Lovett, Barron, et al. (1994) used the present DECTalk-based talking computer system to train the reading and spelling skills of 22 children who had neurological impairments (including spina bifida and hydrocephalus, seizure disorder, brain tumors, cerebral palsy, head injury) or developmental dyslexia. They were reading below the 10th percentile on three standardized tests of word and nonword recognition skill, and measures of intellectual functioning placed them near the low average range. Each child was given 24 lessons, each lasting approximately 45 min. Lovett, Barron, et al. found that both the letter sound ($N = 6$) and onset rime ($N = 6$) experimental groups read significantly more regular TT words at posttest than did an alternative treatment math control group ($N = 5$) or the whole word experimental group ($N = 7$). Furthermore, the three experimental groups were equivalent and superior to the control when the unit of instruction was the same across the groups (i.e., whole word instruction for the exception words in reading, letter-by-letter instruction for the regular and exception words in spelling). Finally, Figure 3 shows evidence of transfer. The letter sound group read significantly more uninstructed words (e.g., *fade*, *shade*, *blade*) that rhymed with the regular words taught during training (e.g., the TT word *made*) than did either the onset rime or the whole word group (all three experimental groups were significantly different from the control).

The Lovett, Barron, et al. (1994) results indicate that computer speech-based instruction is most effective when it involves segmenting syllables into phonemes, onsets, and rimes. Although all three experimental groups learned word recognition skills that they could transfer to the reading of new words with related spelling patterns, the greatest transfer gains were made by the group whose training involved segmenting words at the letter sound level (see also Lovett, Borden, et al., 1994). Although these results may be limited to the small sample of neurologically impaired dyslexic readers as well as the specific nature and duration of the instruction involved in Lovett, Barron, et al., they suggest that extensive training on individual letter sound units and on blending those units into a whole

Figure 3. Transfer to uninstructed regular rhyming words for each instruction condition in Lovett, Barron, Forbes, Cuksts, and Steinbach (1994), with reading posttest means adjusted for pretest performance differences.

word pronunciation may be essential for computer speech feedback to be effective. Talking computers that provide segmental feedback about a word in a sentence context but do not follow it up with additional training involving individual orthographic-phonological units (see, e.g., Olson & Wise, 1992) may be limited in their ability to teach transferable word recognition skills to dyslexic readers.

REFERENCES

- BARRON, R. W., GOLDEN, J. O., SELDON, D. M., TAIT, C. F., MARMUREK, H. H. C., & HAINES, L. P. (1992). Teaching prereading skills with a talking computer: Letter-sound knowledge and print feedback facilitate nonreaders' phonological awareness training. *Reading & Writing, 4*, 179-204.
- BRUCKERT, E., MINOW, M., & TETSCHNER, W. (1983). Three-tiered software and VLSI aid developmental system to read aloud. *Electronics, 56*, 133-138.
- FARMER, M. E., KLEIN, R., & BRYSON, S. E. (1992). Computer-assisted reading: Effects of whole-word feedback on fluency and comprehension in readers with severe disabilities. *Remedial & Special Education, 13*, 50-60.
- GREENE, B. G., LOGAN, J. S., & PISONI, D. B. (1986). Perception of synthetic speech produced automatically by rule: Intelligibility of eight text-to-speech systems. *Behavior Research Methods, Instruments, & Computers, 18*, 100-107.
- KLATT, D. H. (1980). Software for a cascade/parallel format synthesizer. *Journal of the Acoustical Society of America, 67*, 971-995.
- KLATT, D. H. (1987). Review of text-to-speech conversion for English. *Journal of the Acoustical Society of America, 82*, 737-793.
- LEONG, C. K. (1992). Enhancing reading comprehension with text-to-speech (DECTalk) computer system. *Reading & Writing, 4*, 205-217.
- LOVETT, M. W., BARRON, R. W., FORBES, J. E., CUKSTS, B., & STEINBACH, K. A. (1994). Computer speech-based training of literacy skills in neurologically impaired children: A controlled evaluation. *Brain & Language, 47*, 117-154.
- LOVETT, M. W., BORDEN, S. L., DELUCA, T., LACERENZA, L., BENSON, N. J., & BRACKSTONE, D. (1994). Treating the core deficits of developmental dyslexia: Evidence of transfer of learning after phonologically- and strategy-based reading training programs. *Developmental Psychology, 30*, 805-822.
- LOVETT, M. W., RANSBY, M. J., & BARRON, R. W. (1988). Treatment, subtype, and word type effects in dyslexic children's response to remediation. *Brain & Language, 34*, 328-349.
- LOVETT, M. W., RANSBY, M. J., HARDWICK, N., JOHNS, M. S., & DONALDSON, S. A. (1989). Can dyslexia be treated? Treatment-specific and generalized treatment effects in dyslexic children's response to remediation. *Brain & Language, 37*, 90-121.
- LOVETT, M. W., WARREN-CHAPLIN, P. M., RANSBY, M. J., & BORDEN, S. L. (1990). Training the word recognition skills of reading disabled children: Treatment and transfer effects. *Journal of Educational Psychology, 82*, 769-780.
- MINEO, B. A., & CAVALIER, A. R. (1990). Speech output technology in education and rehabilitation: Implications from behavioral research. *Speech-Tech, 2*, 68-75.
- OLOFSSON, A. (1992). Synthetic speech and computer aided reading for reading disabled children. *Reading & Writing, 4*, 165-178.
- OLSON, R. [K.], FOLTZ, G., & WISE, B. [W.] (1986). Reading instruction and remediation with the aid of computer speech. *Behavior Research Methods, Instruments, & Computers, 18*, 93-99.
- OLSON, R. K., & WISE, B. W. (1992). Reading on the computer with orthographic and speech feedback: An overview of the Colorado remediation project. *Reading & Writing, 4*, 107-144.
- TREIMAN, R. (1992). The role of intrasyllabic units in learning to read and spell. In P. B. Gough, L. C. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 65-106). Hillsdale, NJ: Erlbaum.
- VITALE, A. J. (1993). Hardware and software aspects of a speech synthesizer developed for persons with disabilities. *Journal of the American Voice I/O Society, 13*, 27-40.
- WISE, B. W. (1992). Whole words and decoding for short-term learning: Comparisons on a "talking-computer" system. *Journal of Experimental Child Psychology, 54*, 147-167.
- WISE, B. [W.], OLSON, R. [K.], ANSTETT, M., ANDREWS, L., TERJAK, M., SCHNEIDER, V., KOSTUCH, J., & KRIHO, L. (1989). Implementing a long-term computerized remedial reading program with synthetic speech feedback: Hardware, software, and real-world issues. *Behavior Research Methods, Instruments, & Computers, 21*, 173-180.

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