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Acquired alexia: Lessons from successful treatment

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Abstract

Two individuals with anomic aphasia and acquired alexia were each provided treatment for their reading impairment. Although reading of single words in isolation was fairly accurate, their text reading was slow and effortful, including functor substitutions and semantic errors. Prior to treatment, reading reaction times for single words showed grammatical class and word-length effects. Both patients responded positively to a treatment protocol that included two phases: (1) multiple oral rereading of text, and (2) reading phrase-formatted text that had increased spacing between phrasal clauses. Their reading rates for text improved while maintaining good comprehension. Following treatment, reading reaction times for single words showed the elimination of grammatical class and word-length effects, suggesting improved access to word forms, particularly functors. (*JINS*, 1998, *4*, 621–635.)

Keywords: Acquired alexia, Treatment, Aphasia, Dyslexia

INTRODUCTION

Damage to the language-dominant hemisphere that results in aphasia typically disrupts the cognitive processes necessary for reading. Therefore, some degree of alexia is reported in the majority of individuals with acute aphasia (Basso et al., 1979; Wertz et al., 1981) and in chronic aphasia, as well (Webb & Love, 1983). The alexia profiles associated with aphasia may conform to distinct alexia syndromes, but there is not a predictable relationship between aphasia type and alexia syndrome (see, for example, Marshall & Newcombe, 1987). In many (possibly most) cases, alexia associated with aphasia reflects multiple levels of impairment and is characterized as *mixed* alexia. The impairment also has been referred to as *aphasic alexia* because the central language impairment plays a major role in the reading disorder (Friedman et al., 1993; Goodglass, 1993).

In this paper we will describe the assessment and rehabilitation of 2 individuals with anomic aphasia and acquired alexia who responded positively to reading treatment. The cases were noteworthy in that cognitive analyses of reading before and after treatment provided insight into the mechanism for improvement. Before presenting the cases, we will review a model of single-word reading to provide a framework for examining component processes of reading. We will also give an overview of alexia treatment approaches that were considered as treatment was planned.

Acquired alexia can be characterized in a given patient relative to the assumed functional architecture for reading. Single-word reading has been conceived as a series of processes that allow meaning and phonology to be derived from printed words, as shown in Figure 1 (after Ellis, 1993, and Hillis & Caramazza, 1992). Visual input (i.e., letter strings) is transformed into a graphemic representation that is generic in the sense that it is independent of font or style of writing. The graphemic representation is held in a buffer (Caramazza et al., 1996; Hillis & Caramazza, 1992), and is subsequently processed by lexical or nonlexical routes. When reading is accomplished *via* semantics (i.e., the lexical–semantic route), as indicated by the vertical sequence in Figure 1, the representation in the orthographic input lexicon activates the associated semantic information, which in turn addresses the representation in the phonological output lexicon. The phonological representation is held in the phonological output buffer in preparation for speech production. Another lexical route has been proposed (Path (a) in Figure 1) that reflects a direct association between the orthographic input lexicon and the phonological output lexicon that bypasses semantics (i.e., the lexical nonsemantic route; Schwartz et al., 1980). In such cases, the written words are recognized and spoken, but meaning is not addressed. When a word is not accessed *via* the lexical route because it is

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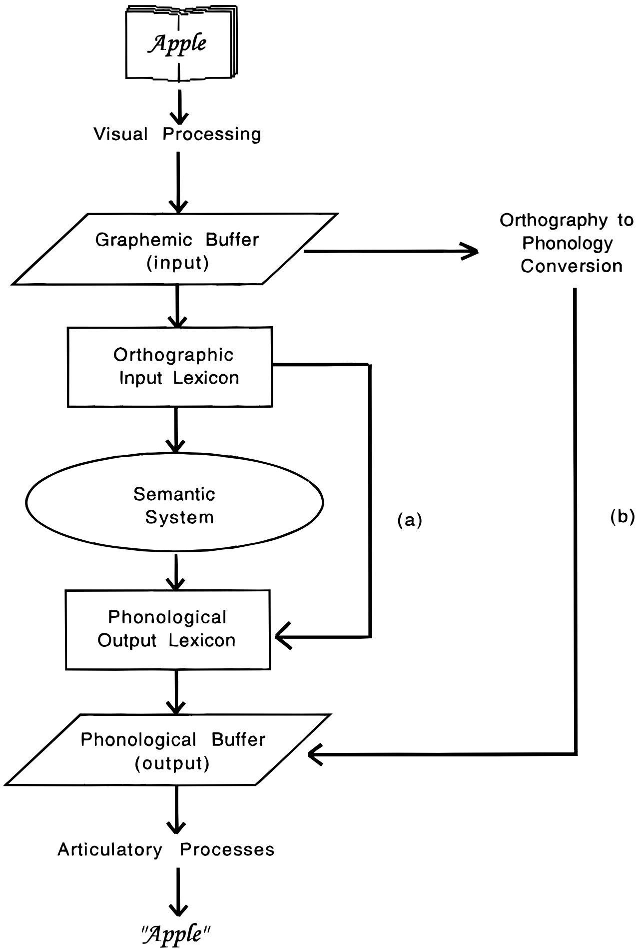

Fig. 1. Model of cognitive processing for single-word reading (after Ellis, 1993 and Hillis & Caramazza, 1992). The vertical path on the left represents the lexical–semantic route; Path (a) indicates the lexical–nonsemantic route; Path (b) indicates the nonlexical route.

unfamiliar or not a real word, it may be read by the nonlexical route that utilizes grapheme-to-phoneme conversion, represented by Path (b) of Figure 1. The phonologically assembled word is ultimately retained in the phonological output buffer prior to speech production in the same manner as words retrieved from the lexicon.

Selective disruption of the component processes for reading can result in qualitatively different forms of alexia that include (but are not limited to) pure alexia, surface alexia, phonological alexia, and deep alexia (see, for reviews, Friedman et al., 1993; Shallice, 1988). Pure alexia, or alexia without agraphia, is characterized by a disruption early in the reading process so that orthographic word forms are not easily recognized (Dejerine, 1891, 1892), and letter-by-letter reading often replaces whole word recognition (Patterson & Kay, 1982). Surface alexia reflects an impairment to the lexical reading route with a resultant overreliance on spelling-to-sound correspondences (i.e., the nonlexical route; Path (b) in Figure 1), so that irregularly spelled words are often regularized (Patterson et al., 1985). In contrast, the nonlexical reading route is impaired in phonological alexia, and deep alexia, so that reading cannot be accomplished by applying common print-to-sound rules (Coltheart, 1980; Glosser & Friedman, 1990). In deep alexia there is additional impairment to the lexical–semantic system, so that semantic errors are common in reading (Coltheart, 1980; Marshall & Newcombe, 1973). Individuals with aphasia may experience partial or complete damage to lexical or nonlexical reading routes, or both, producing a variety of mixed alexia profiles.

The treatment literature for acquired alexia is not extensive, but provides evidence that reading can be improved in cases of relatively well-specified alexia syndromes (for reviews see, Hillis & Caramazza, 1992; Patterson, 1994), and in cases of unspecified alexias associated with aphasia (Holland et al., 1996; Katz & Wertz, 1997). The changes affected by treatment stand in contrast to reports of relatively stable alexia profiles in untreated patients (Behrmann et al., 1990; Wilson, 1994). With some exceptions, including the reported evolution from deep alexia to phonological dyslexia (Klein et al., 1994), it appears that neurologically stable cases of acquired alexia do not appear to change significantly or to evolve without therapeutic efforts.

Treatment derived from a cognitive model of reading typically aims to strengthen those processes and representations that are damaged, and to take advantage of preserved cognitive processes in order to circumvent the weaknesses (Hillis, 1993). Such model-driven treatments primarily have been directed toward improved reading accuracy for a corpus of single words. Positive results have been reported for pure alexia (Daniel et al., 1992; Gonzalez Rothi & Moss, 1992), surface alexia (Coltheart & Byng, 1989; Scott & Byng, 1989), phonological alexia (Moody, 1988a), and deep alexia (DePartz, 1986; Nickels, 1992). Although these studies documented improved single-word reading, little information was provided regarding the impact of these treatments on reading performance for connected text, which often is the ultimate treatment goal.

There are treatment protocols for alexia that targeted text reading rather than single words. Some of these treatments were general, or nonspecific, in the sense that there was no determination of the cognitive processes influenced by the treatment, but they were effective nonetheless. For example, Cherney et al. (1986) reported positive results from an oral reading treatment with 10 individuals with aphasia and alexia whose reading profiles were not detailed, but who were presumably somewhat diverse. The protocol included oral reading of sentences and paragraphs alone and in choral reading with the therapist. The treatment resulted in significant improvement in reading comprehension, and oral and written expression for individuals who were relatively early postonset (3 weeks to 3 months) as well as those who were later postonset (9–29 months). Katz and Wertz (1997) also reported improved reading and language performance in a group of 55 aphasic individuals with unspecified alexia profiles who were at least 5 years postonset. Their patients received computer-provided treatment that included interactive reading tasks arranged along a task continuum that progressed from letter and word matching, to comprehension tasks including single words, questions, and complex sentences. Similar to Cherney et al. (1986), Katz and Wertz documented that improved reading performance was associated with a generalized language improvement as well.

Another text-reading approach was introduced by Moyer (1979) that entailed multiple oral rereading (MOR) of text. The MOR procedure has been shown to improve reading in letter-by-letter readers (Beeson, 1998; Moody,1988b; Tuomainen & Laine, 1991). Repeated oral reading of written passages resulted in improved reading rate for practiced material, and more importantly, it facilitated improved reading rate for new material as well. The treatment effect from MOR was attributed to improved word-form recognition due to the top-down influence provided by the semantic and syntactic context (Beeson, 1998; Tuomainen & Laine, 1991).

Improved accuracy of text reading over single-word reading was recently documented in three individuals with deep dyslexia by Silverberg et al. (1998). Although this was not a treatment study, it provided a comparison of reading accuracy for words presented in isolation and in a paragraph. Silverberg et al. found that oral reading of closed class words (i.e., function words) was better in the context of paragraph reading as opposed to single-word reading. Based on Garrett's model of sentence production (Garrett, 1982), Silverberg et al. argued that syntactic environments provided by text supported the retrieval of function words, whereas content words were not affected in the same manner because they are retrieved independently of the phrase structure. Thus, the cognitive processes active during text reading provided semantic and syntactic context that constrained the lexical retrieval processes in a way that did not occur with single-word reading.

To date, successful treatments for acquired alexias have included procedures that target specific cognitive processes as well as more general approaches which may affect several cognitive processing components for reading, but are relatively nonspecific. The 2 cases that we report here showed alexia profiles that are best characterized as mixed alexia, and warranted treatment for reading text. Our approach might be considered nonspecific in that we could not specify at the outset which cognitive processes were specifically targeted. However, a comparison of our patients' reading profiles before and after treatment provided insight into the probable treatment mechanism.

PATIENT S.V.

Case Report

S.V. was a right-handed woman who experienced a left hemisphere stroke at age 39 years. Her previous medical history was unremarkable; however, 6 weeks after the stroke she was diagnosed with ovarian cancer, which was treated surgically followed by chemotherapy. An acute CT scan and subsequent MRI revealed a large left middle cerebral artery infarct in the left parietal and frontal lobes, and a small area of possible infarct in the right parietal lobe. The stroke was ultimately attributed to hypercoagulability associated with the cancer. Medical records indicated a significant Broca's aphasia and right hemiparesis immediately following the stroke.

S.V. was working as a computer programmer in a research setting at the time of her stroke. Her educational background included two bachelor's degrees (one in anthropology and one in physics) and a master's degree in philosophy. She was clearly a highly intelligent woman who had been an avid reader and writer prior to her stroke.

Initial Assessment

When she was first seen at our clinic at 8 months postonset of stroke, S.V.'s hemiparesis had resolved and her aphasia had evolved to an anomic type with an aphasia quotient of 88.8 on the Western Aphasia Battery (WAB; Kertesz, 1982). At that time, she produced grammatically well-formed utterances with slowness and hesitation. She complained of some word finding difficulty, and was particularly motivated to improve her reading abilities. She indicated that, since her stroke, she felt that she had to read aloud (rather than silently) in order to comprehend the information.

Text Reading–Pretreatment

At 10 months postonset, S.V.'s oral reading accuracy, rate, and comprehension were assessed using the Gray Oral Reading Test–3 (GORT–3; Wiederholt & Bryant, 1992). The GORT–3 consists of passages of increasing length and difficulty (Levels 1 through 13) that are followed by comprehension questions, and is available in equivalent forms, A and B. S.V. was given Form A, Levels 1 to 10 to read aloud. Each passage was followed by multiple choice comprehension questions read aloud by the examiner while visible to S.V. As shown in Figure 2, S.V.'s reading rate was slow compared to the reported range for adults of 150 to 200 words/min for reading aloud (Rayner & Pollatsek, 1989), and was influenced by length and difficulty of the passage. Her mean reading rate for Levels 1 to 5 on the GORT–3 was 40 words/min ($SD = 9$) compared to 22 words/min ($SD = 11$) for the more difficult Levels 6 to 10. Oral reading of 1,065 words on the GORT–3 resulted in 31 uncorrected errors that included functor substitutions (e.g., *can* → *had*), inflectional errors (e.g., *likes* → *liked*), semantic errors (e.g., *tall* → *long*) and visually similar word substitutions (e.g., *cooked* → *cooled*). Despite S.V.'s slow rate and presence of oral reading errors, her reading comprehension was quite good; S.V. made no errors on the questions for the first eight passages.

Reading treatment was not initiated until 2 months after the initial assessment, so Levels 1 to 5 of GORT–3, Form B were administered at 12 months postonset to determine if S.V.'s reading performance was stable. Her mean reading rate was 45 words/min ($SD = 8$), which was similar to the rate of 40 words/min obtained at 10 months postonset on

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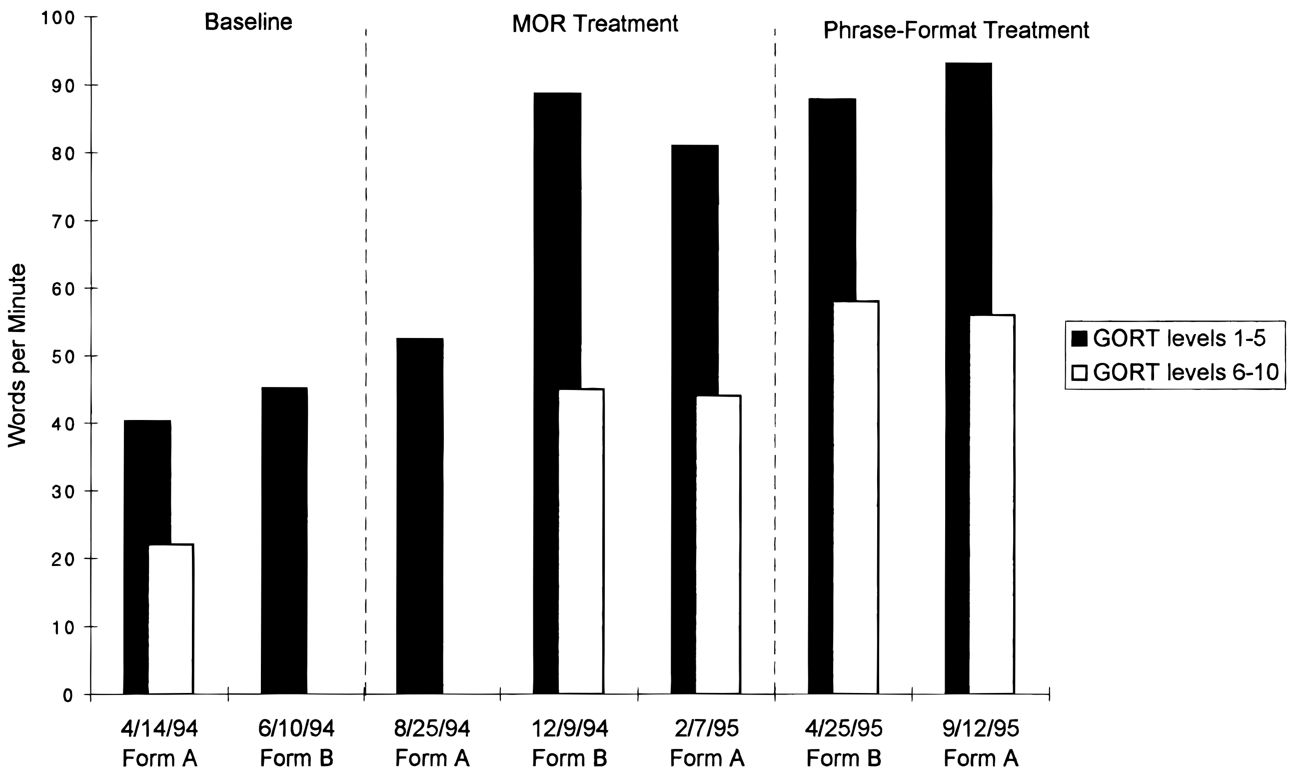

Fig. 2. Reading rates in words per minute on the Gray Oral Reading Test–3 for Patient S.V. before treatment and after multiple oral rereading (MOR) and phrase-formatted text (PF) treatments.

Form A. Oral reading contained errors consistent with those at initial testing, and response to comprehension questions was good. Thus, S.V.'s text reading appeared to be relatively stable. She commented on her reading, "I know nouns. Connecting words give me trouble." This was consistent with her functor substitutions noted in reading text. Occasionally, when S.V. had difficulty reading a word, she appeared to be sounding out the first sound or syllable, and she commented that sometimes she had to sound out words in order to read them. However, in those instances, she did not appear to rely solely on orthography-to-phonology conversion because she did not regularize the pronunciation of irregularly spelled words.

Single Word Reading–Pretreatment

Single, written words from the Psycholinguistic Assessment for Language Processing in Aphasia (PALPA; Kay et al., 1992) were presented individually on a computer screen for reading using the SuperLab program (Cedrus, 1989–1991). Reading accuracy and reaction times were obtained for balanced word lists that controlled various lexical features, so that the following effects were examined: (1) frequency and imageability of nouns; (2) grammatical class (noun, adjective, verb, functor); and (3) word length (four-, five-, six- and seven-letter words). Words were presented in the center of a 38-cm computer screen in 24-point font. Response times between the visual presentation of the word and the initiation of speech to read the word were recorded.[1] Response accuracy was noted for each item. Mean response times were calculated for each word list, after outliers were excluded by setting a rejection boundary of plus or minus 2 standard deviations from the mean of each response subset.

When assessed at 12 months postonset of stroke, reading accuracy for single words was relatively good. S.V. responded correctly to 147 out of 160 (91.8%) single words. There were no marked effects of frequency, imagery, or part of speech on single-word reading accuracy. S.V.'s mean reading reaction time of 1375 ms ($SD = 927$) was slow compared to 3 normal age-matched controls ($M = 620$ ms, $SD = 88$). The controls showed no significant effects for word frequency, imagery, part of speech, or word length. A comparison of reading reaction times for S.V. showed no significant effects for frequency or imagery [$F(1,69) = 2.296$, $p = .134$; $F(1,69) = 0.143$, $p = .706$, respectively]. Although the mean response time for functors (1744 ms) was slower than nouns (1293 ms), adjectives (1348 ms),

[1] Reaction times were obtained by manual keypress at the initiation of the response, rather than a voice-activated trigger. We recognize that recorded reaction times include the experimenter's reaction time to the initiation of speech production which may result in slower than actual reaction times. However, our data from 6 normal control participants showed consistent reaction time across word lengths, no effects for grammatical class, imagery, or frequency; in addition, standard deviations were smaller than 65 ms (which includes both experimenter and participant variability).

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and verbs (1401 ms), the difference was not statistically significant [$F(3,67) = 1.879$, $p = 0.142$]. A word-length effect was noted in that reading reaction times were incrementally longer as words increased in length from four to seven letters ($r = .295$, $p < .001$; see Figure 3). Spelling regularity was not tested with controlled lists; however, there was no evidence from S.V.'s single-word or text reading that irregularly spelled words posed any particular difficulty. S.V. was able to read some nonwords (14/24 correct), albeit slowly, demonstrating some ability to derive phonology from orthography.

Pretreatment Reading Summary

Slowed reading rate and paralexias in reading text were the most notable features of S.V.'s reading. The observed word length effect of about 132 ms for each additional letter suggested some disruption of whole-word recognition; however, the increased reading time per word was not of the magnitude typically observed in letter-by-letter reading (Behrmann et al., 1990; Shallice, 1988), nor was there evidence of overt letter-by-letter reading. Increased response times for longer words may have reflected her efforts to self-cue by derived phonology. There was no evidence that S.V. relied on the nonlexical route exclusively, however, because she did not make regularization errors on irregularly spelled words. In addition, her nonword reading indicated that her ability to convert orthography to phonology was partially impaired.

S.V.'s subjective complaints of more difficulty with "connecting words" were consistent with the functor substitutions in text reading and the longer (although not significant) response times for functors. S.V.'s paralexic errors were not mirrored in her spoken utterances. Her speech was characterized by hesitation and occasional word-finding difficulties, but did not typically contain functor substitutions, morphological, or semantic errors. In summary, S.V.'s reading profile shared some features observed in pure alexia (word-length effect), deep alexia (semantic errors and grammatical class effect), and surface alexia (some phonemic self-cuing), but did not conform to any of the classic alexia syndromes.

Reading Treatment

The goal of reading treatment for S.V. was to improve her reading rate with a relatively high level of accuracy and comprehension. Oral reading was the selected approach because it was S.V.'s preferred manner of reading and it allowed us to monitor her reading accuracy. S.V.'s word length effect suggested that she had some disruption in direct access to the orthographic input lexicon, so the multiple oral

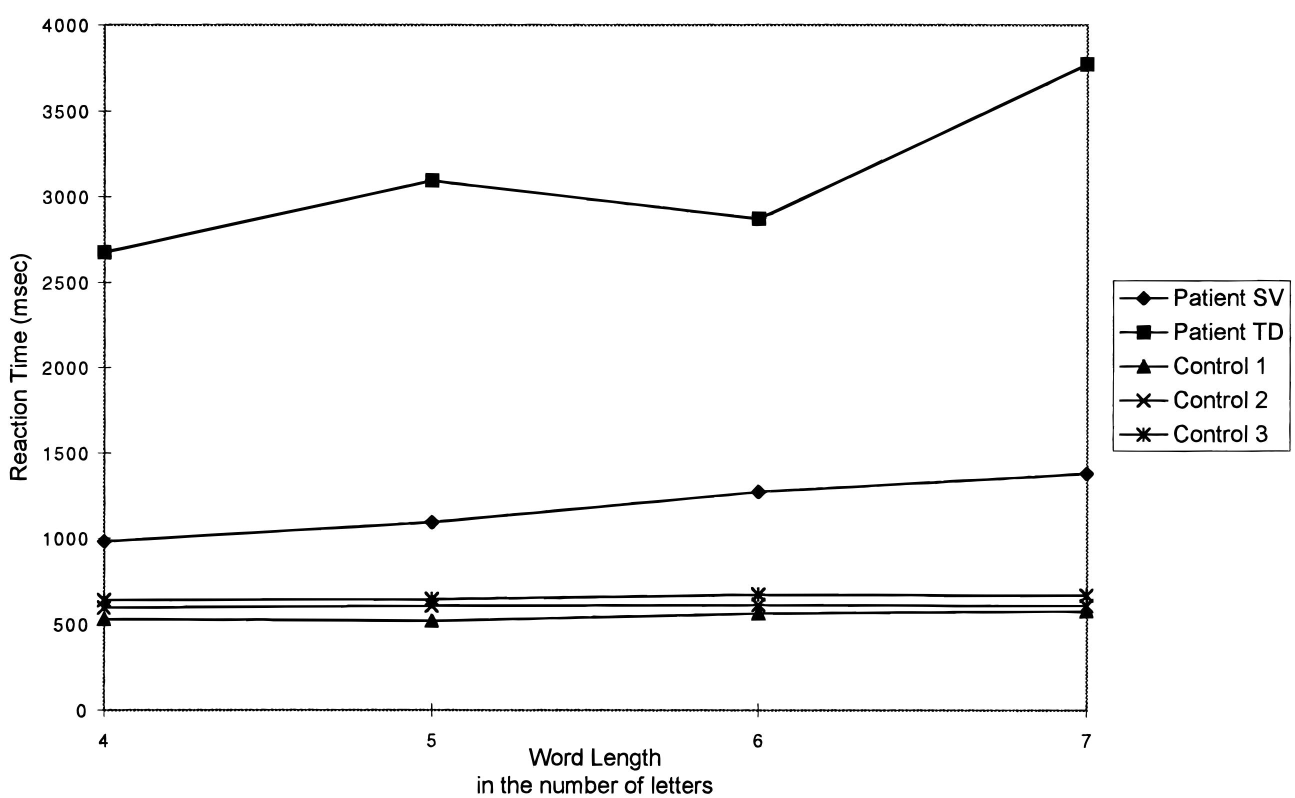

Fig. 3. Reading reaction time by word length obtained from patients S.V. and T.D. before treatment for reading and from three control participants.

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reading approach (MOR) was considered worthy of trial because it had been shown to be effective in increasing reading rate in other patients with disrupted access to the orthographic input lexicon, specifically, letter-by-letter readers (Beeson, 1998; Tuomainen & Laine, 1991). Additionally, the syntactic constraints offered by text were considered potentially facilitative for the reading of function words which were particularly vulnerable to error in S.V. (Silverberg et al., 1998).

Multiple Oral Rereading

The oral reading treatment program was initiated with S.V. at 12 months postonset of stroke. She was seen once per week to monitor the treatment protocol, which relied heavily on daily reading homework. The MOR procedure was adapted from Moyer (1979) and was consistent with that used by Beeson (1998) to increase reading rate in a letter-by-letter reader. S.V. was given a passage from the Scientific Research Associates (SRA; 1978) series to read aloud during a therapy session. Her oral reading rate was determined for the selected passage, and then the passage was repeatedly read aloud with the goal of increased reading rate with improved or maintained accuracy. When the passage was reread during the weekly therapy session, the clinician guided S.V. to correct reading errors on-line. On some occasions, the clinician presented S.V. with a list of words that she had misread in text; when those error words were presented individually, S.V. rarely misread them. S.V. was instructed to spend at least 30 min per day reading the passage; she kept a reading log to confirm this homework regimen. When reading rate for practiced text reached a target goal of 100 words/min, it was retired and another passage was introduced for repeated oral reading homework.

Over the course of 10 months of treatment, S.V. achieved the goal of 100 words/min on eight SRA passages. Her reading rates for new SRA texts indicated that her reading rate for new text was improving as well, as shown in Figure 4. Her reading rate was sampled using alternate forms of the GORT–3 after 2, 6, and 10 months of treatment. As shown in Figure 2, marked improvement in reading rate was recorded after 6 months of MOR treatment (12/9/94). S.V. had doubled her pretreatment reading rate for the easier GORT–3 Levels 1 to 5 (40 words/min → 87 words/min) and the more difficult Levels 6 to 10 (22 words/min → 45 words/min). After that time, reading rates appeared to reach a plateau both on the SRA passages and with additional GORT–3 testing (2/7/95 on Figure 2).

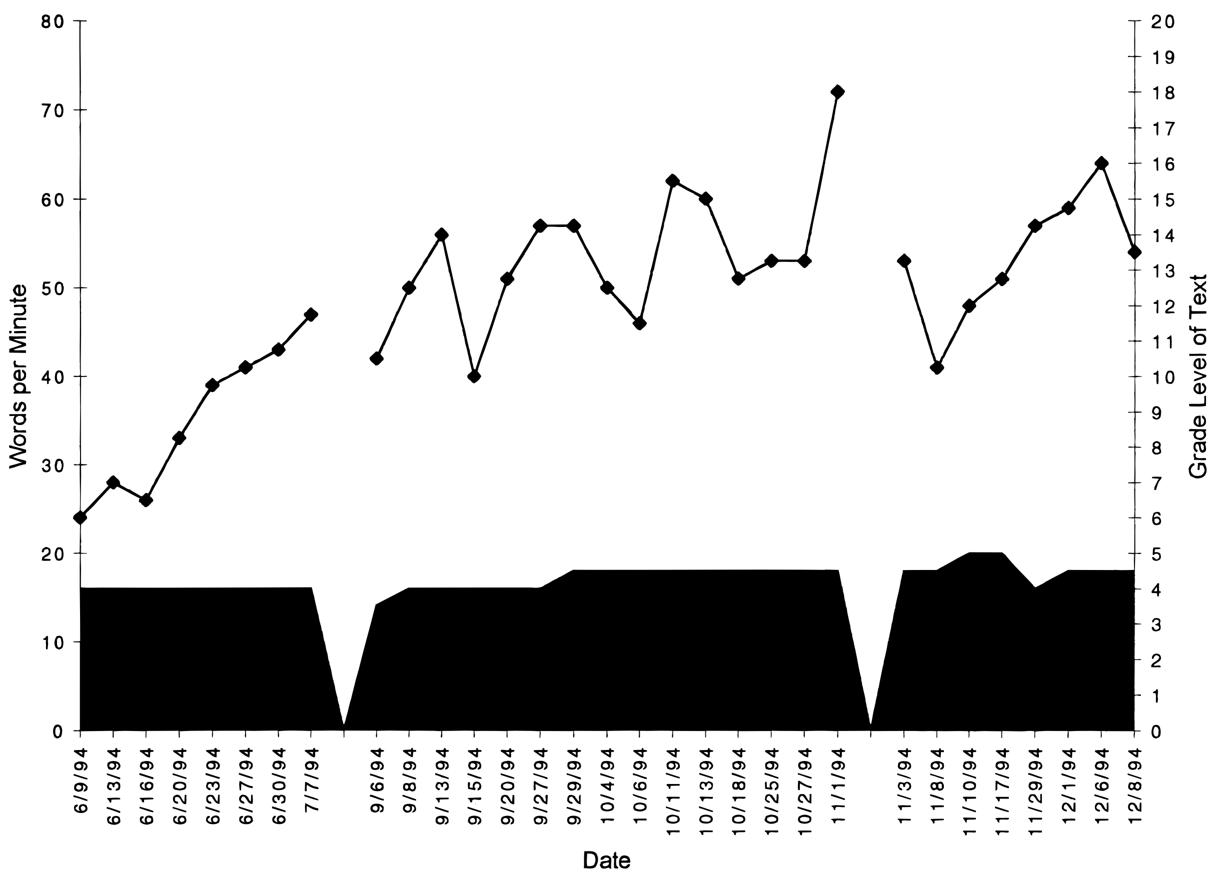

Fig. 4. S.V.'s reading rates for previously unread passages from the SRA reading program, sampled over 6 months. The darkened region indicates the designated grade level of the SRA text.

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Phrase-Formatted Text

At 22 months postonset, the treatment approach was changed in an effort to achieve additional reading improvement. A treatment approach using specially formatted text was inspired by the work of Bever and colleagues who found that spacing text to isolate major phrases increased its readability for college students who were average or poor readers (Bever et al., 1990, 1992; Jandreau & Bever, 1992; Jandreau et al., 1986). Their phrase-formatted text was generated using a computer algorithm that parsed sentences into grammatical phrases and inserted an extra space between phrases as was done in this sentence. A phrase-formatted textbook entitled *Introducing computers* (Blissmer, 1990) that was used by Bever et al. (1990) was the material used for this treatment phase with S.V. During each weekly therapy session, her reading rate was obtained for a section of previously unread text in the book. Homework consisted of reading the text at least 30 min per day. By this treatment phase, S.V. was increasingly comfortable reading silently, so her homework reading was accomplished silently or aloud, however she preferred. Regularly formatted SRA passages were presented at least once per month to sample reading performance for standard text.

S.V.'s reading rate was sampled using the GORT–3 after 2 and 7 months of reading phrase-formatted text. As shown in Figure 2, her reading rates were relatively unchanged for Levels 1 to 5, but improved for Levels 6 to 10, so that her final reading rates were 93 words/min (*SD* = 15) and 56 words/min (*SD* = 20), respectively. These rates were consistent with those obtained during weekly sessions for previously unread text for which S.V.'s rates ranged from 90 to 110 words/min for relatively easy reading material to 45 to 65 words/min for difficult material. This congruity served to alleviate concern that improved rate on the GORT–R passages was simply due to familiarity.

Single Word Reading—Posttreatment

Single-word reading was reassessed *via* computer presentation at the end of treatment; that is, after 15 months of reading treatment. Response accuracy was again quite high, with 157 correct responses out of 160 words controlled for frequency, imagery, and grammatical class. As shown in Figure 5, reaction time for functors had improved more than other parts of speech (1744 ms to 1105 ms) so that there was little difference in response times as a function of grammatical class. There was also no longer a significant word length effect for reading reaction time ($r = .04$, $p = .639$), as shown in Figure 6.

Follow-up

Some follow-up sessions were spent exploring remaining clinical questions for S.V. First, we suspected that her maximum oral reading rate of about 110 words/min might reflect the upper limit of her speech production capabili-

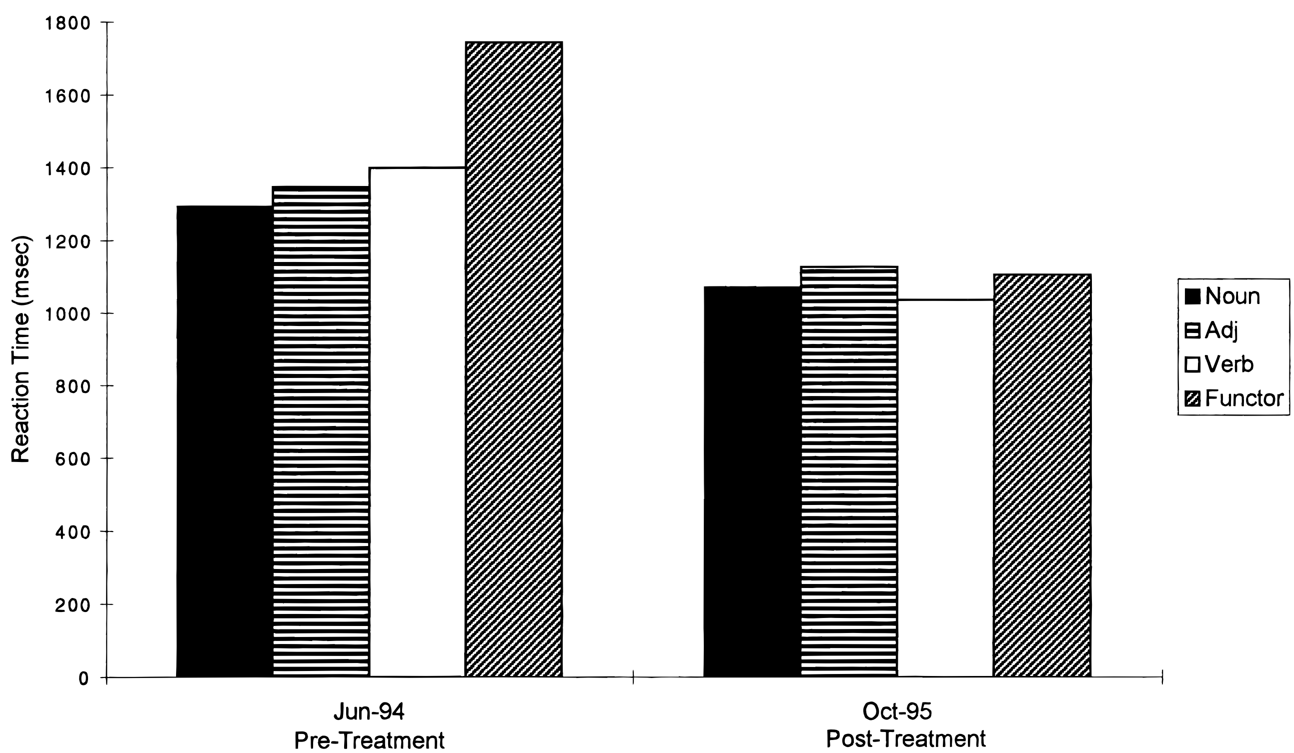

Fig. 5. Reading reaction times for nouns, adjectives, verbs, and functors obtained from S.V. before and after treatment for reading.

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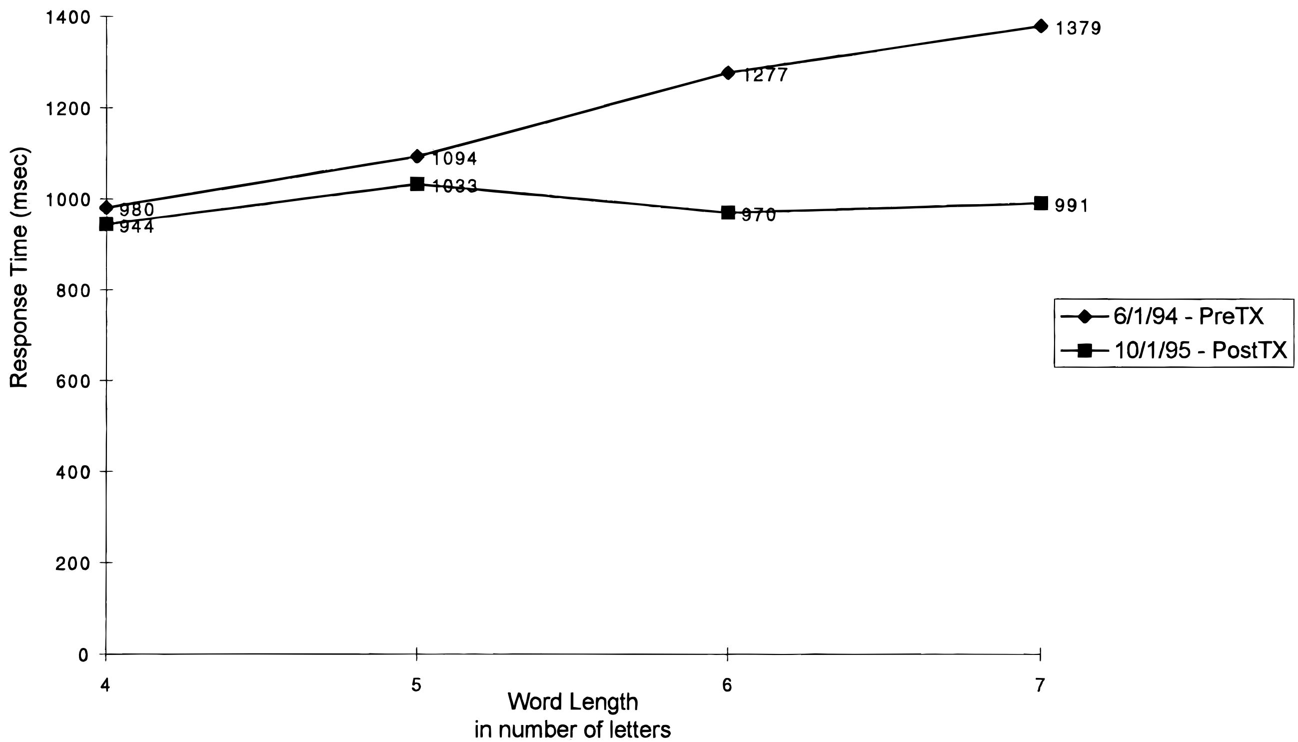

Fig. 6. Reading reaction times as a function of word length obtained from S.V. before and after treatment for reading.

ties. She was presented several written passages of well-known text and asked to read them aloud. Her fastest reading rate was 125 words/min for *The Pledge of Allegiance*, which appeared to confirm that the upper limits of her oral reading rates were constrained by her speech production rate. This rate was slow relative to normative oral reading rates for unfamiliar material (150–200 words/min; Rayner & Pollatsek, 1989), with faster rates expected for familiar material.

Several therapy sessions were directed toward silent reading, encouraging S.V. to depart from word-by-word reading and to reduce subvocalization of written words. In that context, she was in fact able to increase her silent reading rate to a range of 150 to 180 words/min, with good reading comprehension for new material. However, S.V. ultimately decided that reading rates in excess of about 120 words/min required so much effort that they were not tolerable for pleasure reading. Therefore, she was satisfied with pleasure reading rates that appeared to hover around 100 words/min. Continued contact with S.V. has shown maintenance of posttreatment reading rates, continued daily reading for pleasure, and successful return to part-time work.

The Western Aphasia Battery was readministered to S.V. at 21 months postonset. Her aphasia quotient had improved from 88.8 before treatment to 94.7, showing improvement in naming and repetition abilities. Although this improvement was modest, it was deemed significant in that it was greater than the standard error of measurement for the WAB of about 5 AQ points (calculated from Shewan & Kertesz, 1980).

Discussion

S.V.'s reading treatment was not initiated until 1 year after her stroke. Clearly that was a time when physiological restitution had long since taken place. It can be assumed that if S.V. had made no effort to improve her reading at that time, it would not have changed significantly. Indeed, she showed relatively stable performance during repeated testing spanning a 2-month pretreatment period. S.V. indicated that reading was laborious and effortful, and that she had not resumed her prestroke pleasure reading. The multiple oral re-reading approach was considered an appropriate initial treatment for S.V. because it allowed her to develop competence with a selected passage supported by the familiarity of the content and syntactic structure. As observed in letter-by-letter readers (Beeson, 1998; Moyer, 1979), increased reading rate for practiced reading material appeared to facilitate reading rate for new reading material in S.V. as well.

After institution of the phrase-formatted text, S.V. made some additional gains in reading rate for more difficult text, but she appeared to have been nearing her ceiling performance of about 100 words/min for the easier text. It appeared that her oral reading rate was constrained by her slow speech production rate, which was notable in conversation and on picture description tasks. If she was reading aloud as fast as she could produce the words, then treatment with the phrase-formatted text was not given an adequate evaluation with S.V. because of the ceiling effect for easier text.

S.V. initially complained that functors were difficult for her, and her text reading showed functor errors as well as

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derivational errors. It was intriguing to note that she improved her reading reaction time for functors to a greater extent than nouns, adjectives, and verbs. This may suggest that the repeated reading was particularly helpful to stabilize her recognition of the function words. Although all words in a given reading passage received multiple exposure as the passage was repeatedly read for the MOR procedure, function words received the greatest exposure because they are the most frequent words. Another explanation for the differential effect for functors is derived from Garrett's (1992) speech production model, suggesting that the syntactic frames provided by sentences facilitated word recognition for function words to a greater extent than content words, as Silverberg et al. (1998) showed in their patients with deep dyslexia.

S.V.'s reduction of the word-length effect also was of interest. The presence of a word-length effect prior to treatment suggested that S.V. employed serial decoding of words to some extent. Clinical observation and self-report suggested that when S.V. failed to access the word form, she employed the nonlexical route to retrieve some phonology for the word, and did not use a letter-by-letter reading approach. The partial phonological information may have served to guide her access to the orthographic input lexicon, with longer words requiring more time to decode than shorter words. The disappearance of the word-length effect after treatment suggested a shift to whole word recognition that was not reliant on serial decoding. In summary, S.V.'s improved reading rate appeared to reflect a generalized improvement in whole word recognition and a specific improvement in associating written functors to their corresponding phonological representations.

PATIENT T.D.

Case Report

T.D. was a right-handed man with a history of hypertension who experienced an intracranial hemorrhagic stroke at age 51 years. An acute CT head scan revealed a 4×6 cm hematoma in the left posterior temporoparietal region. Medical records indicated paraphasic, fluent aphasia that evolved to anomic aphasia by 3 weeks postonset. He had adequate auditory comprehension for short statements, legible printing, profound confrontation naming deficits, and severe reading comprehension and written formulation deficits. In addition, impulsivity, poor memory and attention, and difficulties with problem-solving were reported. An acute right visual field defect was reported that resolved by 6 weeks postonset. T.D. had a bachelor's degree in business and reported a varied employment background that included work as a county sheriff. At the time of his stroke he was a part-time insurance adjuster.

Initial Assessment

T.D. was first seen at our clinic 3 months postonset of stroke. At that time, he obtained an overall Aphasia Quotient of 90.3 on the WAB (Kertesz, 1982), with a profile consistent with anomic aphasia. Subtest results showed mild deficits in auditory comprehension, repetition, and language formulation, with naming most impaired. Word-finding and circumlocutory responses were noted. Reading difficulty was T.D.'s primary complaint at that time. He reported that he did not read because he was so slow and did not comprehend well. Additional neuropsychological testing revealed reduced digit span forward (raw score = 7; 28th percentile), reduced visual memory span forward (raw score = 6; 12th percentile), and impaired written calculation for single digit multiplication (5/10 correct) and single digit division (5/11 correct).

Text Reading

T.D.'s reading was assessed at 5 months postonset of stroke with the GORT–3, Form A. Oral reading rate was slow with a mean of 58 words/min ($SD = 11$) for Levels 1 to 5, and 50 words/min ($SD = 3$) for Levels 6 to 8 (Figure 7). Comprehension was mildly impaired as indicated by a mean comprehension rate of 78%. T.D. spontaneously corrected many of his reading errors during text reading. On the GORT–3 Levels 1 to 8, he made 23 uncorrected errors out of 763 words that included functor substitutions (e.g., *under* → *between*) and semantic errors (e.g., *good* → *okay*). In order to determine if T.D.'s reading was improving spontaneously, baseline reading samples were obtained for 4 weeks using SRA text at Grade Level 3.5. As shown in Figure 7, T.D.'s performance was relatively stable at 57, 69, 59, and 61 words/min ($M = 61.9$; $SD = 6.2$).

Single-Word Reading–Pretreatment

Single-word reading was assessed by computer presentation as described for Patient S.V. T.D. responded accurately to 138 out of 160 words controlled for frequency, imagery, and grammatical class. There were no marked effects of frequency, imagery, or part of speech on single-word reading accuracy. A comparison of reading reaction times showed no significant effect for word frequency [$F(1,65) = 1.159$, $p = .286$], but low imagery words were read more slowly than high imagery words [$F(1,65) = 8.076$, $p = .006$]. Mean reaction times for functors (6460 ms) were significantly longer than for nouns (2397 ms), adjectives (3842 ms), and verbs (2888 ms); [$F(3,60) = 6.460$, $p = .001$; Tukey *post hoc* tests $p < .05$]. As shown in Figure 3, seven-letter words were read more slowly than four-, five-, and six-letter words, ($t(47) = -5.369$, $t(56) = -4.976$, $t(64) = -5.036$, respectively, $ps < .001$), but there was not a linear relationship between word length and reaction time ($r = .154$, $p = .067$). Spelling regularity was not tested with controlled lists, and like S.V., T.D. gave no evidence of regularizing irregularly spelled words. He read 22 out of 24 nonwords correctly.

Pretreatment Reading Summary

T.D.'s reading was similar to that of S.V. in that he was very slow, but fairly accurate, although he showed some reduced

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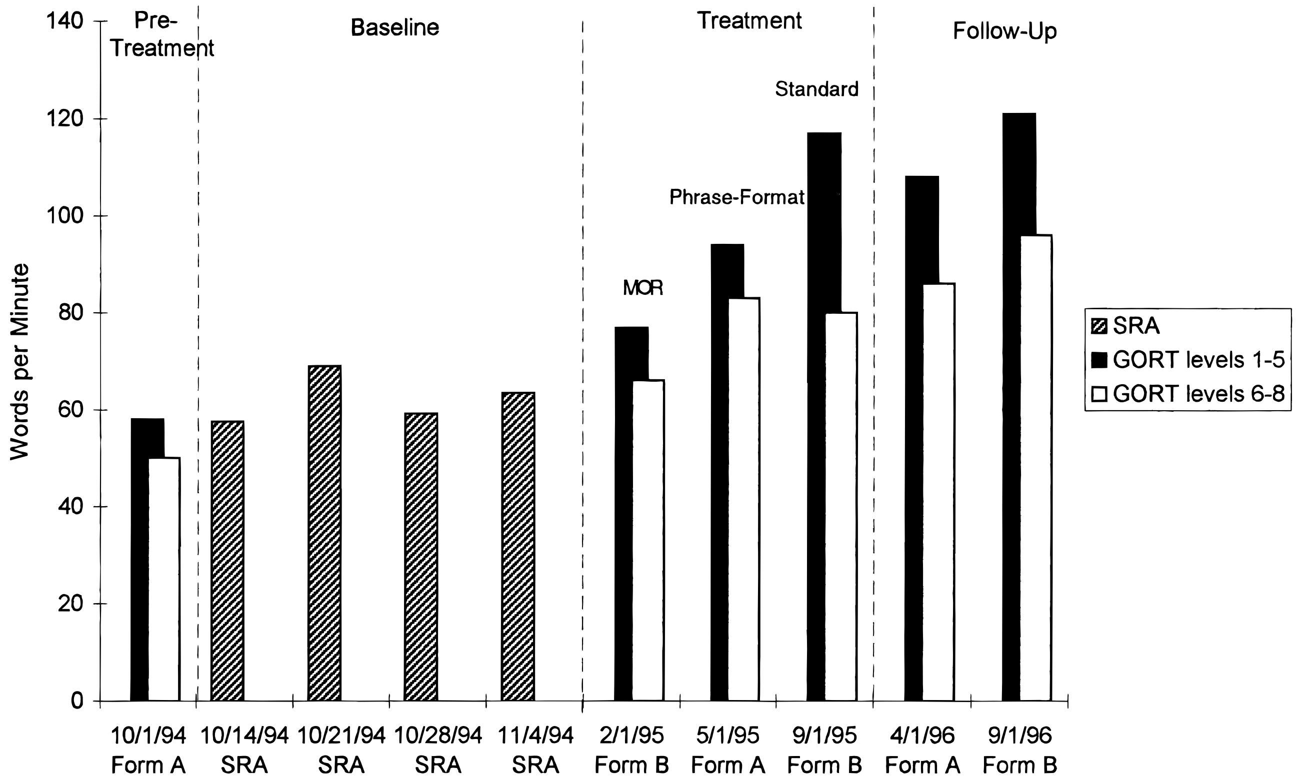

Fig. 7. Reading rates in words per minute on the Gray Oral Reading Test–3 for Patient T.D. before treatment and after multiple oral rereading (MOR) and phrase-formatted text (PF) treatments, after reading standard formatted text, and at two follow-up visits.

comprehension as measured by the GORT–3. His oral reading of text included substitution errors for verbs and functors in particular, and many errors were self-corrected as he read. Some of the verb substitutions were semantically related to the target word. Single word reading was remarkable in that functors clearly required longer reaction times than other parts of speech. T.D. also showed slower reading reaction times for reading low imagery *versus* high imagery words. There was a word length effect for seven-letter words compared to shorter words. T.D. had the ability to derive phonology from graphemes as shown by his ability to read nonwords. T.D.'s expressive language problems were relatively mild, with word-finding problems primarily for content words, as is typical in anomic aphasia. As noted with S.V., T.D.'s paralexic errors were not mirrored by paraphasias in his spoken utterances. For that reason, it seemed most appropriate to assume that his reading impairment stemmed largely from weakened access to the orthographic input lexicon, rather than his semantic system or phonological output lexicon.

Reading Treatment–Multiple Oral Rereading

The MOR treatment was initiated with T.D. at 6 months post-onset. He was seen weekly for a 30-min session to monitor his reading of SRA text at Grade Levels 3.5 and 4.0. The treatment program was essentially identical to that described for S.V., wherein SRA texts were assigned for repeated oral reading as homework. Reading rates were monitored for practiced and new text. Over the course of treatment T.D. achieved the reading rate of 100 words/min for six SRA passages, and his reading of new SRA texts indicated a slow improvement in reading rate for new text in a manner similar to S.V.

After 3 months of MOR treatment, T.D. was administered the GORT–3, Form B. For Levels 1 to 5, he averaged 77 words/min ($SD = 12$), an improvement from 58 words/min before treatment (Figure 7). Reading rate improved for Levels 6 to 8 from 50 to 66 wpm ($SD = 15$). His response to comprehension questions was 85% correct.

Phrase-Formatted Text

Treatment for the next 3 months was switched to the phrase-formatted text. T.D. was highly interested in reading the *Introducing computers* text that was used with S.V. He had studied data processing in college prior to his stroke, and was anxious to rejoin the work force; therefore he welcomed this shift to more substantive reading material. T.D.'s daily homework was to read for at least 30 min from the phrase-formatted text. During his weekly session T.D. read the text aloud and each deviation from print was noted. He continued to make some paralexic errors, but was invariably able to read aloud previously misread words when they were presented to him singly. During this treatment phase, T.D. reported that he started to read for pleasure. After 3 months of reading phrase-formatted text, readministration of the GORT–3, Form A, showed T.D.'s mean reading rate was 94 words/min (*SD* = 7) for Levels 1 to 5, and 83 words/min (*SD* = 4) for Levels 6 to 8 (Figure 7). Comprehension remained above 80% correct.

Single-Word Reading–Posttreatment

After the MOR and phrase-formatted treatments, T.D.'s single-word reading was reexamined. At that time he was 12 months postonset of stroke, and had received 6 months of reading treatment. An examination of reading reaction time by word length showed a faster reading rate for all word lengths, and seven-letter words were no longer slower than four-letter words (Figure 8). As shown in Figure 9, reaction times were improved for all word classes, but functors in particular were no longer read more slowly than other parts of speech (*M* = 2501 ms). T.D.'s reading of nonwords was qualitatively different at this time, he lexicalized 47% of the nonwords, for example *kep* was pronounced as *keep*. Although T.D. was reminded during the task that these were not real words, and stated that he understood that, he continued to lexicalize about half of the nonwords.

Follow-up Treatment

After 3 months of reading phrase-formatted text, T.D. had finished the computer text, and was ready to continue reading college-level material. We took the opportunity to compare the effects of reading from a standard formatted text to his previous treatments. T.D. selected an introductory social psychology text from the campus bookstore to read as homework. For 4 months, he continued to read text on a daily basis for at least 30 min. By that time, T.D. was also reading other material for pleasure in addition to his homework. As shown in Figure 6, T.D. showed continued improvement in his oral reading rate for easier text on the GORT–3 (Levels 1 to 5), but no improvement for the more difficult text (Levels 6 to 8) after 4 months of reading standard formatted text. His reading comprehension scores remained high.

T.D. continued to read the social psychology text at home until he finished the book, and also read for pleasure over the next 7 months. His reading rate was tested at almost 2 years postonset of stroke, and again at 2 years, 4 months postonset. The measures showed that T.D. maintained his improved oral reading rate around 100 to 120 words/min (Figure 7). Because T.D. had been exposed to the GORT text on three occasions by this time, his reading rate was also tested with completely new material. His reading rate for SRA text at 4.5 level was 97.1 words/min and for col-

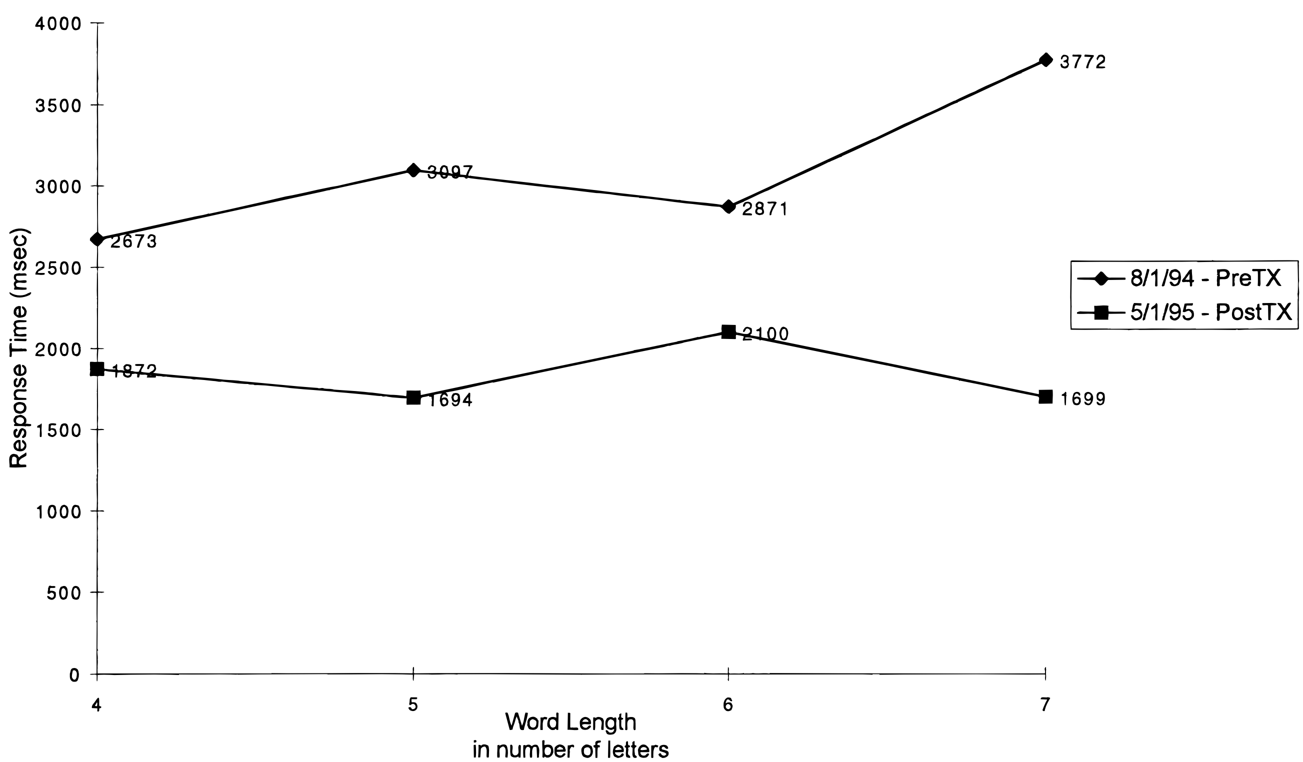

Fig. 8. Reading reaction times as a function of word length obtained from T.D. before and after treatment for reading.

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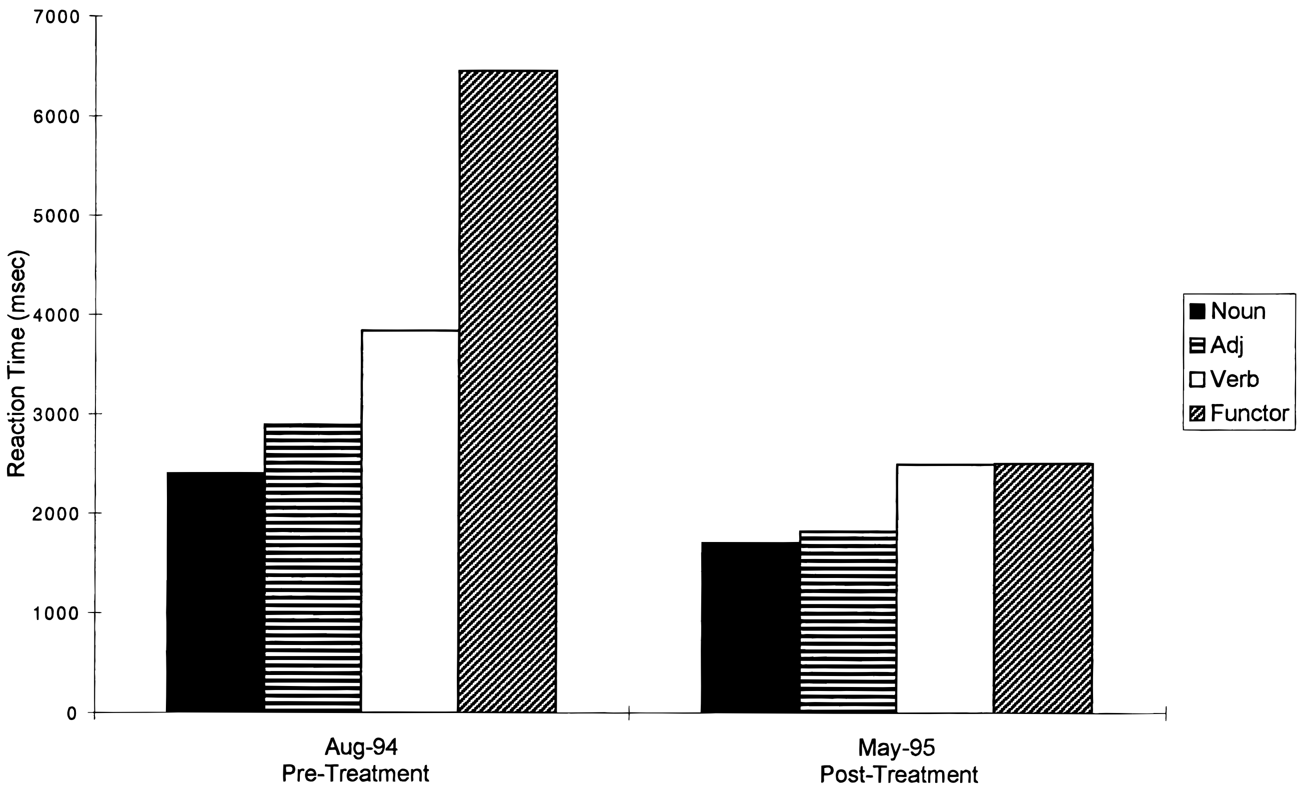

Fig. 9. Reading reaction times for nouns, adjectives, verbs, and functors obtained from T.D. before and after treatment for reading.

lege level text was 73.4 words/min, thus confirming his overall improvement in reading rate.

Follow-up Testing

T.D.'s oral language skills were reassessed with the WAB (Kertesz, 1982) after the MOR and PFT treatments at 12 months postonset. His Aphasia Quotient increased significantly from 90.3 to 98.3, with improvements noted particularly in confrontation naming and smaller improvements in comprehension and repetition. Selected neuropsychological tests were readministered during the follow-up period (June 1996) to examine performance on nonlinguistic tasks. T.D.'s performance remained impaired on digit span forward (raw score = 7; 28th percentile), visual memory span forward (raw score = 6; 12th percentile), and written calculation for single-digit multiplication (5/10) and single-digit division (6/11).

Discussion

T.D.'s response to treatment was similar in many ways to S.V.'s. Although he was treated nearer to the onset of his stroke, he showed stable reading performance over 4 weeks prior to treatment. T.D. showed improved reading rate with the MOR reading approach, and, unlike S.V., showed notable improvement when he shifted to reading the phrase-formatted text. At the single-word level, T.D.'s reading rate for functors was significantly faster after treatment, and seven-letter words no longer had increased reaction times. In summary, T.D.'s improved reading rate for text appeared to reflect improved word recognition, particularly for functors. Improved access to the orthographic input lexicon was further supported by T.D.'s (posttreatment) tendency to lexicalize nonwords, suggesting that he could not suppress lexical candidates that were visually similar to nonwords. It is noteworthy that T.D.'s reading improvement occurred in contrast to consistently impaired performance on visual and verbal span tasks, as well as single-digit written calculation, thus suggesting a treatment-specific effect.

GENERAL DISCUSSION

The case studies presented here are of interest from two perspectives: First, they provide support for treatment of acquired alexia using a format that relies primarily on structured reading tasks undertaken at home; and second, they provide insight into changes that might underlie the treatment effects. It is our clinical experience that there are many individuals like S.V. and T.D. who complain of significant residual reading impairments after their spoken language has recovered to a functional level. Because the concern about reading is more likely to surface late in the recovery period, at a time when most patients are no longer receiving clinical services, implementation of treatment protocols for text reading is not common. Our patients received treatment over a relatively long period of time, but the actual clinical contact time was only once per week. S.V. was seen for approximately 70 hr of treatment over 19 months. We suspected that 1-hr sessions were not necessary, so T.D. was seen for 30-min sessions over 1 year, totaling about 22 hr of treatment. Thus, our findings with S.V. and T.D. show that such treatments can be effective and efficient, and worthy of consideration for similar patients.

Both S.V. and T.D. improved their reading rates and maintained good comprehension in response to a sequence of multiple oral rereading treatment followed by treatment with phrase-formatted text. After treatment, single word reaction times showed greater improvement in the recognition of functors than for other word classes. Additionally, the fading of the word length effect suggested improved access to word forms, so that serial decoding of single words was no longer evident. Our treatment design did not allow us to determine the relative contribution of the MOR and PFT treatments to the single-word reaction times, and we recognize in retrospect that we should have obtained reaction times between the two treatments. Our failure to do so reflected the fact that our patients' responses to treatment were not simply a confirmation of our *a priori* assumptions; rather they were "leading" us to understand the treatment mechanism. While acknowledging that our treatment sequence fell short of an ideal single-subject design, we remain impressed by the changes observed in S.V. and T.D.

The fact that S.V. and T.D.'s single-word reading profiles and text reading rates both changed suggested that the treatment had a specific rehabilitative effect. That is, treatment served to strengthen weakened processes or representations necessary for reading. Change may have been achieved either by improving access to the input lexicon, or strengthening the connection between the corresponding representations in the orthographic input and phonological output lexicons, or both. The greater improvement for functors suggests something more specific than a generalized improvement in word recognition. We favor the perspective of Silverberg et al. that the syntactic constraints of sentence frames support recognition of closed class words over open class words. Thus, repeated reading of text may have stabilized access to the relatively fragile closed class words. We speculate that the PFT also may have specifically assisted the processing of functors by providing phrase boundaries that made the syntactic roles of functors more salient or comprehensible. T.D.'s continued improvement when reading standard format text (after MOR and PFT treatments) serves to temper our claims to some extent. The critical feature of the treatment may be the reestablishment of text reading on a regular basis, either using MOR, PFT, or simply oral reading as reported by Cherney et al. (1986).

S.V. and T.D. both received the MOR treatment prior to PFT treatment, thus obviating the chance to examine treatment order effects. We do not know if PFT reading would have been as effective as MOR if it had been administered first. However, it was our clinical intuition that rereading a selected passage was a critical transition from nonreading to reading in S.V. and T.D., as it was in a letter-by-letter reader treated with MOR (Beeson, 1998). The MOR procedure allowed the clinician to assist the patient in gaining familiarity with the passage during the treatment session so that homework assignments did not require patients to struggle through new text on their own. Clearly additional treatment research is necessary to better understand the relative impact of text versus single-word treatment, MOR *versus* PFT, and treatment order effects.

Treatment that focuses on text rather than single words is somewhat contrary to the traditional treatment hierarchy that would place reading single words as a precursor to reading sentences. However, as we consider reading processes in the context of text reading rather than single word identification, we appreciate the increased potential for interactive contributions. Although reading is dependent upon visual input, the top-down semantic and syntactic processes influence information processing and may constrain lexical selection in a helpful way. It is likely that individuals with acquired alexia have only partial lexical information on some occasions, and their text reading is supported by supplemental input provided in the form of partial phonological information (derived *via* the orthography to phonology conversion route), semantic information (from contextual meaning and semantic knowledge), and syntactic constraints on lexical selection. We appreciate the fact that text reading must require some criterion level of graphemic, phonological, and semantic–syntactic competence below which rehabilitation of text reading is unlikely. Our point is that there may be many treatment cases in which a single word approach is selected over text reading when the latter may reap greater benefit.

Finally, it is worthy of note that both S.V. and T.D. significantly improved their aphasia quotients over the course of reading treatment. The finding is consistent with that of Cherney et al. (1986) who reported overall language improvement associated with oral reading in individuals with aphasia. Nevertheless, the improvement was surprising given that both S.V. and T.D. were already approaching the performance ceiling for the WAB prior to treatment. We again consider the potential for interactive processing during oral reading to strengthen partial or degraded lexical information. If the treatment benefit is not purely at the level of the orthographic input lexicon, then it is reasonable to expect benefits for language processing by other modalities as well.

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