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Repetition priming in oral text reading: a therapeutic strategy for phonologic text alexia

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Abstract

Background—Phonologic text alexia (PhTA) is a reading disorder in which reading of pseudowords is impaired, but reading of real words is impaired only when reading text. Oral reading accuracy remains well preserved when words are presented individually, but when presented in text the part-of-speech effect that is often seen in phonologic alexia (PhA) emerges.

Aims—To determine whether repetition priming could strengthen and/or maintain the activation of words during text reading.

Methods & Procedures—We trained NYR, a patient with PhTA, to use a strategy, Sentence Building, designed to improve accuracy of reading words in text. The strategy required NYR to first read the initial word, and then build up the sentence by adding on sequential words, in a step-wise manner, utilizing the benefits of repetition priming to enhance accuracy.

Outcomes & Results—When using the strategy, NYR displayed improved accuracy not only for sentences she practiced using the strategy, but unpracticed sentences as well. Additionally, NYR performed better on a test of comprehension when using the strategy, as compared to without the strategy.

Conclusions—In light of research linking repetition priming to increased neural processing efficiency, our results suggest that use of this compensatory strategy improves reading accuracy and comprehension by temporarily boosting phonologic activation levels.

Keywords

phonologic text alexia; repetition priming; aphasia; alexia; rehabilitation

Introduction

The concept that phonologic text alexia (PhTA) is a mild form of phonologic alexia (PhA) and the related idea that PhTA and PhA exist on a continuum were first articulated over a decade ago (Friedman & Lott, 1995). Patients with PhTA were described as having impaired pseudoword reading but relatively intact single word oral reading, including function word (functor) reading. In contrast, their oral text reading, particularly of functors and affixes in

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text, is impaired (Friedman & Lott, 1995; Friedman, 1996a). As in the more widely reported case of PhA, associated deficits typically include impaired pseudoword repetition and decreased digit and word spans resulting from a general phonologic impairment believed to underlie PhA (see *Cognitive Neuropsychology*, 13(6), 1996 special issue on Phonological Dyslexia). Much of the literature on PhA concerns functor and content word reading in *isolation* (e.g., Beauvois & Dérouesné, 1979; Coslett, Rothi, & Heilman, 1984; Friedman, 1995; Funnell, 1983; Patterson, 1982), or at the end of a single sentence (ERP studies, e.g., Münte et al., 2001; ter Keurs, Brown, Hagoort, & Stegeman, 1999). Far fewer studies, however, assess functor and content word reading within *text*. The small number of reported probable PhTA cases may thus reflect limited assessment procedures. Although it is currently uncommon to find reports of an alexic patient with poor pseudoword reading combined with text-only impairments in functor reading, in terms of clinical presentation, it is primarily that combination that distinguishes PhTA from PhA.

It has also been suggested (Glosser & Friedman, 1990) that PhA lies on a continuum with deep alexia. Deep alexia is a reading impairment in which the poor pseudoword and functor reading seen in phonologic alexia is coupled with the production of semantic paralexias (e.g. “table” is read as “chair”). It is claimed that PhA represents less severe phonologic impairment, and deep alexia represents more severe phonologic impairment coupled with concomitant semantic impairment. Placing PhTA on a continuum with PhA extends the severity spectrum of acquired phonologic impairment, connecting PhTA to deep dyslexia, with PhA marking the mid-point (see also Friedman, 1996b and Crisp & Lambon Ralph, 2006 for more discussion of the continuum connecting PhA and deep dyslexia). That is, PhTA represents the mildest impairment on the continuum of phonologic-based reading impairment, while PhA represents a more severe impairment on this continuum, with deep alexia as the endpoint.

The deficits associated with PhTA suggest that the phonologic representations of functors may not be activated completely or at normal speed (Beeson & Insalaco, 1998; Friederici, 1995; Swinney, Zurif, & Cutler, 1980). If activation were reduced or slow, accuracy of single functor reading would be unaffected, while functor reading in text would be impeded by interference from surrounding words – the pattern of PhTA. Alternatively, phonologic representations of functors may be activated normally, but this activation might decay at a pathologically rapid rate. If the problem is slowed or weakened initial activation of phonologic representations, then therapies that allow for quicker/easier activation should be of benefit, whereas rapidly decaying representations should benefit from therapies that prolong activation. The current study examines the efficacy of a therapy that is based upon a technique that provides a temporary boost to activation levels, i.e. repetition priming. The repetition-priming phenomenon facilitates the processing of a particular stimulus, given previous exposure to that stimulus. The effects are immediate, transitory, and item specific (Dean & Young, 1996; Scarborough, Cortese, & Scarborough, 1977), with a neural signature of diminished neural activity for the repeated stimulus (Demb et al., 1995; Gabrieli, Desmond, Demb, & Wagner, 1996; Wig, Grafton, Demos, & Kelley, 2005), potentially linked to increased efficiency of neural processing (Poldrack & Gabrieli, 2001).

We hypothesized that for a PhTA patient with intact single word reading, repetition priming could be utilized to speed or strengthen the activation of functors and affixes during text reading, preventing interference from more richly represented content words during sentence processing. Because the effects of repetition priming are immediate and transitory, we created a treatment program in which we trained the use of a strategy, called ‘Sentence Building’ that a PhTA patient could employ whenever she reads. The patient is taught to read text by building sentences in steps. For example, for the target sentence, “*The employees at the zoo knew not to tease the animals*”, although the sentence is presented in

its entirety, the patient is instructed to first read “*The*”, then “*The employees*”, then “*The employees at*” and so on until the entire sentence has been read. We predict that the repetition of the words as the sentences are built will help speed and strengthen activation of the words on the subsequent steps.

The specific predictions to be addressed in this study are 1) repetition priming, as achieved through cued sentence building, will improve oral sentence reading accuracy, 2) following a period of sentence building training, the patient will independently apply the strategy to *trained* sentences presented in free vision, resulting in greater oral reading accuracy and 3) following a period of sentence building training, the patient will independently apply the strategy to *untrained* sentences presented in free vision, resulting in greater oral reading accuracy.

Materials and methods

Patient NYR

NYR is a 68-year-old right-handed Caucasian woman, with 18 years formal education. Prior to her stroke, NYR worked as a reading teacher. She had no history of reading or learning disabilities. In late December 1996, at the age of 59, she suffered an infarct in the distribution of the left middle cerebral artery, affecting nearly all of the left frontal lobe, as well as posterior temporoparietal regions, including part of Wernicke’s area, and part of the left thalamus (see Figure 1).

Immediately after her stroke, NYR reportedly presented with a Broca’s aphasia. By the time she joined the current study, approximately 8 years later, her speech was fluent and grammatical, although she continued to produce frequent phonemic paraphasias. In addition, she presented with poor repetition, and mild word finding and auditory comprehension deficits. Table 1 provides her scores on a range of language and cognitive measures.

NYR’s reading performance was assessed through a battery of standardized tests and non-standardized tests created in our lab. She showed no effects of concreteness (concrete words 24/30; abstract words 22/30) or regularity (regular 15/30; exception 16/30). Her ability to recognize words spelled aloud to her was much more impaired than her ability to read them (6/40 vs. 31/40), a pattern frequently observed in patients with PhTA due to their underlying phonologic impairment. She displayed impaired pseudoword reading (2/20) relative to matched real word reading (15/20). We were unable to detect a part-of-speech effect in reading words presented individually in either accuracy (concrete nouns 33/41, adjectives 34/41, abstract nouns 32/41, verbs 28/41, and functors 40/41) or reaction time ($F(4, 171) = 0.661, p > .50$). When reading text, however, a part-of-speech effect did emerge, as illustrated by an analysis of her error patterns when reading selected passages from the Gray Oral Reading Test (GORT III; Wiederholt and Bryant, 1992): nouns 44/49 (90%), adjectives 10/11 (91%), verbs 29/44 (66%), functors 83/117 (71%). Her text reading errors primarily involved functor and verb errors and substitutions. Reading comprehension was fairly good as assessed by the Sentence/Paragraph subtest of the Boston Diagnostic Aphasia Examination (BDAE 3; Goodglass et al, 2001) (9/10), and selected subtests of the Reading Comprehension Battery for Aphasia (RCBA, LaPointe and Horner, 1984) (51/60). Assessment by the Gates-MacGinitie Reading test (1965), however, revealed less accurate comprehension (18/36) on lengthier material (20–26 words/passage).

NYR’s non reading-specific phonologic skills were also assessed. Her digit span raw scores of 5 forward/1 backward were low compared to visual span raw scores of 7 forward/5 backward. Pseudoword repetition was also poor (12/30). NYR’s combination of reduced digit and word spans, poor pseudoword reading and repetition, relatively intact single word

reading, and impaired text reading led to a diagnosis of phonologic text alexia (Friedman, 1996a).

Stimuli

Four sets (A, B, C and Control) of ten sentences were created, three used to teach and test the strategy (A–C), and one to assess whether NYR could successfully use the strategy to read untrained sentences (Control). All sentences contained eleven words. No content or functor word, with the exception of *the*, *a*, and *an*, was repeated across the sentences. Only one inflected form of each content word was allowed throughout the entire corpus of sentences (i.e., because *seen* was used, neither *see* nor *saw* was used). In order to ensure equivalent difficulty, content word frequency, overall number of syllables and affixes, and grammatical structure were matched across the sets. Each sentence (or utterance, *u*) was rated for grammatical structure based on Szmrecsányi's (2004) Index of Syntactic Complexity (ISC) formula:

$$\text{ISC}(u) = 2 \times n(u, \text{SUB}) + 2 \times n(u, \text{WH}) + n(u, \text{VF}) + n(u, \text{NP})$$

SUB = subordinating conjunctions (e.g., because, since, as, when, that, etc.); WH = WH-pronouns (e.g., who, whose, whom, which); VF = verb forms, both finite and non-finite; NP = noun phrases; *n* = number of instances. To facilitate matching average ISC across the sets, the sentences were created in quartets (one for each set) that shared the same basic structural components. For example, for a structural component such as a prepositional functor, where A has *above*, B has *near*, C has *along*, and the control set has *below*. The only exception to this rule was a single quartet, in which all four sentences had an infinitive form (*to speak*, *to hide*, *to look*, *to play*), and thus an overlapping functor. The number of sentences with compound functors (e.g., *sometimes*) and interrogatives was matched across sets. Each set contained 49–50 functors, 12–13 verbs, 1–2 adverbs ending in *-ly*, and 23–25 nouns, as well as 19–20 counts of affixes (excluding affixes on functors).

Procedure

All treatment and probe tests were programmed and presented using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) on a PC laptop. Responses were digitally recorded. Prior to treatment, baseline performance on each of the four sets was assessed three times, to check stability. Each sentence was presented whole, in free vision. At least a week separated each baseline measurement. In addition, accuracy and speed of reading the individually presented words within each set were assessed. Response time was determined with Praat 4.3.19, a speech analysis program that provides spectrograms of responses (Boersma & Weenink, 2005).

During the training period, NYR attended two-hour sessions twice a week. The three training sets (A–C) were trained on a rotating basis. A given set was trained for two sessions consecutively. During training, each sentence appeared in its entirety on the screen in black *Courier New* font, size 18. Sentences were then “built” on the screen by changing the font color of the words to be read to magenta (via a keyboard press by the experimenter). One additional word became magenta on each successive trial until all eleven words were magenta. NYR was instructed to read aloud all of, and only, the magenta words. If NYR did not use the building technique, she was cued to do so, though this happened very infrequently. During training, when NYR made errors, the experimenter provided the correct word, and had NYR repeat it. NYR was neither encouraged nor discouraged from using the strategy at home, nor did she receive any structured ‘homework’ involving the strategy, as our goal was to measure the immediate and presumably transient effects of repetition

priming. In order to address our first hypothesis that repetition priming, as achieved through cued sentence building, will improve oral sentence reading accuracy, we scored her final reading of fully-built sentences during training trials.

For probe testing, NYR was instructed to build the sentences: “Use the strategy you’ve learned in treatment to read these sentences out loud as accurately as possible.” The sentences were presented in free vision, without the aid of the font color change, and without experimenter feedback. Probe testing consisted of either the set practiced that day (practiced sentences, P) or one of the other two training sets not practiced that specific day (non-practiced sentences, NP). The order of presentation of P and NP probes alternated each week, as did which unpracticed set was probed. Scoring was based solely on the accuracy of the *final* reading of each complete sentence, not on accuracy during the building steps. Training continued until NYR read 90% of the words correctly on her reading of the fully built NP sentences for two consecutive weeks (criterion).

The probe schedule was structured in this fashion in order to promote transfer of sentence building from cued presentation to free vision presentation, the goal of our second hypothesis. Probing at the end of the session maximized the likelihood that NYR would use the strategy consistently and without any prompting since she would have just practiced it, albeit with the benefit of visual and verbal cues. The P probes evaluated transfer to free vision presentation on a simple level, to sentences practiced that day, while the NP probes evaluated transfer to free vision presentation on a higher level, to sentences that were not practiced on that day. To ensure that we were assessing NYR’s transfer of the strategy from cued to free vision presentation, as opposed to her ability to read sentences on which she had just spent the session receiving assistance and feedback, criterion performance was based on NP, rather than P sentences. Our probe schedule was similar to the more customary probing at the beginning of the session in the sense that criterion was based on performance reading sentences that were trained during a *previous* session. Note that probe test data were only used to monitor transfer of sentence building to free vision presentation; the second hypothesis, that NYR will *independently* apply sentence building to trained sentences and improve her oral reading accuracy, was addressed by analyzing her accuracy reading the trained sentences when they were administered during a post-treatment session conducted under baseline conditions, not at the end of a training session.

To stringently address our third hypothesis, that NYR will *independently* apply sentence building to untrained sentences and improve oral reading accuracy, we chose to assess performance on a Control Set that was never probe tested at the end of a session, but presented only during pre and post testing conducted under baseline conditions. We did not regularly probe untrained sentences because we have found that sentences in particular (as opposed to single words) become quite familiar after the frequent, repeated exposure of daily probing, rendering them no longer truly untrained.

To test for any general improvement on individual word reading, all words contained in the sentences of each set were presented individually for oral reading, both before and after completion of treatment. To test for any general improvement in text reading, as opposed to strategy-specific improvement, NYR’s performance in reading both with and without the strategy was assessed in a separate post-testing session after the treatment program was completed.

In addition to assessing the impact of strategy use on reading accuracy, we also did a post-hoc assessment of its impact on reading comprehension. At the conclusion of treatment and testing, we administered a multiple-choice reading comprehension test. The test consisted of 10–13-word sentences, each with three possible one-word choices for the final word (cloze),

divided into 10 sentences at each of three levels of difficulty, for a total of 30 sentences. Difficulty was graded in terms of the familiarity, concreteness, and imaginability of the majority of the words in the sentences (rankings obtained from the MRC Psycholinguistic Database, Version 2 (Wilson, 1988)). In Level 1, most of the words in the sentences (aside from functors and proper names) had familiarity, concreteness, and imaginability ratings ranging from 500–700. In Level 2, the range was lowered to 300–500, and for Level 3, it was lowered further to 100–300. Given the small number of possible words for use in Level 3, several words were chosen in the 100–300 range on two of the three variables (familiarity, concreteness, and imaginability), but the 300–500 range for the remaining one. No content words were repeated across sentences, repetition of functors was minimized, and foils were chosen so as to be both semantically related to words in the sentence, and syntactically legal as the cloze, so as not to make the answer obvious from the final three words of the sentence alone. The sentences were designed to require only basic world knowledge, without requiring any specialized education. NYR was tested over the course of two sessions, in which the 30 sentences were first randomized and then divided into two halves. During the first session, NYR was instructed to read each sentence and then select the correct answer. She was explicitly instructed to use the strategy to build the first 15 sentences and to not use the strategy on the second 15 sentences. During the second session, this pattern was reversed, and accuracy for the 30 sentences, both using the strategy and not, was tabulated according to Level.

Results

Baseline Testing

We assessed NYR's baseline reading of the words contained within the four Sets, when the words were presented individually. Accuracy was high (mean accuracy: 86%, $SD = 2.1$), and was equivalent across Sets, $\chi^2 (3, N = 407) = 1.11, p > 0.50$. No part-of-speech effect was apparent in her accuracy (functors 84% correct, verbs 78% correct, adverbs 71% correct, adjectives 93% correct, nouns 81% correct) nor in her reaction times (functors 1.62 s, verbs 1.66 s, adverbs 1.81 s, adjectives, 1.56 s, nouns 1.73 s)

We also assessed NYR's baseline reading of the four Sets of sentences. Accuracy was equivalent across the four Sets (mean accuracy, given as a percentage of the 11 words per sentence, SD s in parentheses): A = 66(12); B = 61(8.6); C = 58(18); Control = 61(12); [$F (3, 36) = .626, p > 0.60$]. Accuracy was stable across the three baselines (baseline 1: 63% correct, baseline 2: 59% correct, baseline 3: 62% correct). When performance reading the sentences was broken down by grammatical class, a part-of-speech effect emerged (functors 52% correct, verbs 65% correct, correct, adverbs 62% correct, adjectives 78% and nouns 86% correct; [nouns versus functors: $\chi^2 (2, N = 888) = 94.32, p < .001$]). In addition, NYR made errors on 25% of the affixes. Thus, as with her initial performance during diagnostic testing, NYR had a part-of-speech effect in text, but not for individually presented words, even when measured in reaction time.

Treatment data

To address the hypothesis that repetition priming, as achieved through cued sentence building, improves oral reading accuracy, we compared NYR's baseline sentence reading accuracy (averaged across the three baselines) to her first reading of each sentence via cued sentence building (her performance reading fully-built sentences during each set's initial training session). NYR's accuracy reading Set A improved from 66% to 88%, Set B from 61% to 93% and Set C from 58% to 90% correct. A 2×3 ANOVA showed a highly significant main effect of test time (baseline versus first training session) on reading

accuracy ($F(1, 27) = 129.775, p < .001$). Thus, the very first time NYR completely built each set of sentences her reading accuracy was significantly higher than it was at baseline.

To further assess the effects of repetition priming, we evaluated NYR's word reading accuracy as a function of position within the sentence. On completely built sentences, words in initial positions receive greater priming than do words in final positions. If repetition priming works, it stands to reason that those words receiving greater priming would be read more accurately than those receiving less priming. We compared the number of correctly read words in the 1st, 2nd and 3rd positions to those in the 9th, 10th and 11th positions. Since we did not control for part of speech across sentence position, we first made this comparison on her baseline performance. At baseline, NYR read words in initial positions significantly *less* accurately than words in final positions (initial words: 162/270 (60%), final words: 190/270 (70%); $\chi^2 = 6.4, p < .02$). We then made this comparison on her fully-built training sentences on her final six NP probes¹. Words in initial positions were read more accurately than those in final positions when using sentence building (initial words: 163/180 (91%), final words: 151/180 (84%)), although this trend did not reach significance. ($\chi^2 = 3.0, p > .05$). Thus, the greater priming of words in initial positions, achieved through sentence building, resulted in a tendency to read initial words more accurately than final words, despite her greater difficulty with initial words prior to treatment.

Despite criterion-level oral reading accuracy during cued presentation, NYR's oral reading accuracy during initial free vision presentations (both P and NP probes) remained below criterion level (see initial probes in Fig 2). The order in which the sets were trained and probed was such that the probe 1 measured performance on sentences that, at that point in time, were not yet trained. Note that performance on probe 1 remained within baseline range. The fact that reading of untrained, and even trained, sentences presented in free vision remained below criterion-level performance, even when measured at the end of a treatment session in which she was cued to use sentence building, suggests that continued training was warranted in order to optimize the transfer of sentence building from cued presentation to free vision presentation.

Post-treatment testing

NYR reached criterion after 24 training sessions (12 weeks). To test for any general improvement in single word reading, we re-assessed NYR's performance reading the words from the four Sets when presented individually. Accuracy remained high (mean accuracy: 90%, $SD = 2.1$) and equivalent across Sets, $\chi^2(3, N = 406) = 1.75, p > .05$. There was no significant improvement in reading the individually presented words over her pre-training accuracy, for either the trained or untrained words (McNemar $p > .05$, respectively). An ANOVA found no significant difference in post-treatment reaction time among the four Sets ($p > .05$), and paired t-tests of pre- and post-treatment reaction times for reading individually presented words showed no significant change either across the four Sets combined, $t(3) = 0.10, p > .25$, or when excluding the Control Set, $t(2) = 1.12, p > .10$. Thus, the treatment had no measurable effect on reading trained or untrained words when presented individually.

To evaluate the hypotheses that, following treatment, independent sentence building would result in significantly more accurate reading of both trained and untrained sentences, we reassessed NYR's sentence reading in a session devoted to post-testing and conducted under baseline conditions. In order to assess her natural tendency to use the strategy, NYR was instructed to use "whatever method" she wanted to read the sentences as accurately as

¹These stimuli were chosen for analysis because they were read via proficient use of the sentence building strategy and they did not receive any other priming that day.

possible. With this minimal prompt, NYR chose to use the building strategy on all the sentences. An ANOVA of post-treatment performance using the strategy revealed no significant difference in accuracy between the four sets (mean accuracy (%) (*SD*): A = 94(11); B = 82(16); C = 87(14); Control = 82(12); $F(3, 36) = 1.80, p > .10$). We conducted a 2×4 ANOVA to look at the effects of test time (average of baseline performance versus post-training) and Set. As can be seen in Figure 3, the simple main effect of test time on accuracy was highly significant, $F(1, 36) = 1845, p < .0001$. The interaction between test time and Set was not significant, $F(3, 36) = 1.07, p = .38$; thus, NYR improved equally on all sentences, trained and untrained.

While reading accuracy improved overall when using the strategy to read the four Sets of sentences, NYR continued to read functors more poorly than any other grammatical class (functors 82% correct, verbs 94% correct, adverbs 86% correct, adjectives 95% correct, nouns 96% correct; [nouns versus functors $\chi^2(2, N=296) = 9.72, p < .01$]). Her average error rate on affixes decreased from 25% pre-treatment to 15%.

To test for any general improvement in text reading as opposed to strategy-specific improvement, we compared NYR's post-treatment performance reading aloud sentences when using the strategy with performance when not using the strategy. NYR was retested reading sentences from training Set B and the Control set (sets in which her accuracy was identical when using the strategy), but this time with the explicit instruction to not use the building strategy. As shown in Figure 4, oral reading of the trained sentences was not significantly better when using the strategy as compared with not using the strategy (82% versus 85%, respectively; Wilcoxon signed rank test, 1-tailed $p = .09$). Reading of the untrained sentences, however, was significantly more accurate when using the strategy as compared with not using it (82% versus 69%, respectively; Wilcoxon signed rank test, 1-tailed, $p < .05$). Importantly, reading of the untrained sentences *without* the strategy was *not* significantly more accurate following treatment, compared with before treatment (69% versus 62%, respectively; Wilcoxon signed rank test, $p > .10$). Thus, while improvement on the trained sentences might be attributed to familiarity rather than use of the strategy, the fact that NYR significantly improved her accuracy reading untrained sentences *only* when using the strategy suggests that this improvement can be primarily attributed to the use of sentence building, rather than to any general reading improvement achieved during the treatment.

Because the strategy was so successful for reading untrained sentences, we chose to conduct a post-hoc assessment of its effect on reading *comprehension* in addition to its effect on accuracy. NYR completed a reading comprehension test in two conditions; in one condition she was instructed to use the building strategy and in the other she was explicitly instructed to not use it. As shown in Figure 5, when using the building strategy, NYR correctly answered 25 out of 30 sentences, whereas when reading without the strategy, she correctly answered only 20 out of 30. The difference was significant (McNemar, 1-tailed $p < .05$). The difference tended to be greater for the more difficult items: Level 1: 10/10 with strategy versus 9/10 without strategy; Levels 2 and 3: 9/10 and 6/10 with strategy, respectively versus 7/10 and 4/10 without the strategy, respectively).

Following treatment, we re-administered several language tests. There were few notable changes. While her auditory comprehension score on the BDAE complex ideational material subtest improved (from 6/12 to 10/12), her score on the auditory comprehension version of Gates-MacGinitie actually *decreased* (from 23/36 to 18/36). Performance on written comprehension version of the Gates-MacGinitie fell slightly, although average time to read the silently read passages dropped precipitously (see Table 1 for scores). Pseudoword repetition improved slightly (from 12/30 to 17/30). There was no change in her reading of

pseudoword or matched-word reading, or in her reading of individually presented words varying in part of speech. In addition to the internal measures we used for experimental control, we also evaluated performance before and after treatment on a task not expected to improve with treatment, picture naming. NYR demonstrated equivalent performance on the Boston Naming Test before and after treatment (33/60 and 34/60, respectively).

Discussion

In this study, we trained a patient with PhTA in the successful use of a reading strategy, Sentence Building, designed to improve accuracy of text reading via repetition priming.

The finding that NYR demonstrated significantly greater oral sentence reading accuracy on her reading of fully-built sentences during her first treatment sessions supports our first hypothesis that repetition priming, achieved via cued sentence building, improves oral reading accuracy. An analysis of words as a function of their position within the sentence further supports the claim that repetition priming improves reading accuracy. NYR tended to read words that received the greatest amount of repetition priming (i.e. those occurring earlier in the sentence) more accurately than those receiving the least amount of repetition priming (i.e. those occurring later in the sentence), a pattern different from her baseline reading. Together, these findings suggest not only that repetition priming improves reading accuracy, but also that greater priming improves reading accuracy to a greater degree.

Despite NYR's improved accuracy reading sentences when she was cued to use sentence building, her initial performance reading those same sentences when they were presented in free vision was less accurate. A period of training was necessary before NYR reached 90% accuracy on reading trained sentences presented in free vision. Not surprisingly, and consistent with the notion of repetition priming, accuracy on sentences tested the day they were practiced (i.e. received additional priming) reached 90% accuracy after only six sessions, while sentences tested on days that they were not practiced (i.e. did not receive additional priming) required 21 sessions before reaching 90% accuracy.

In post-testing, NYR independently applied sentence building to both trained and untrained sentences and demonstrated improved oral reading accuracy. Comparison of her accuracy reading both with and without sentence building, however, showed that trained, but not untrained, sentences were read just as accurately without the strategy. This pattern suggests that she had simply become familiar with the trained sentences. Since untrained sentences were administered only at pre and post-testing, improvement on those sentences cannot be attributed to familiarity due to repeated exposure. She did not demonstrate significant improvement in her reaction time for reading the words from those sentences when they were presented individually (her accuracy for individually presented words was already high, though not quite at ceiling, prior to treatment, in consonance with her diagnosis of PhTA), suggesting that this improvement did not result from any general improvement in single word reading. Nor can this improvement be attributed to a general improvement in sentence reading. When reading untrained sentences after treatment *without* the strategy, NYR was *not* significantly more accurate than she was at baseline. She was, however, significantly more accurate reading untrained sentences when she used the strategy compared to when she did not. In addition, NYR performed better on a test of reading comprehension when using the building strategy, as compared to her performance when not using the strategy.

A frequent problem in treatment is the lack of transfer of a trained strategy from the treatment stimuli to novel stimuli. As discussed above, NYR successfully accomplished this transfer to novel stimuli that were matched to her trained stimuli (i.e. the Control Set of

sentences), but she did not use sentence building on her external reading measures. An unexpected outcome on these external measures, however, was an apparent improvement in both her oral and silent reading *speed*, as measured by the GORT and the Gates-MacGinitie respectively. This pattern of increased reading speed was also apparent in her post-treatment reading of the untrained sentences when she did not use the strategy (from a mean response time of 19.6 s/sentence before treatment to 16 s/sentence after treatment). NYR did not, however, demonstrate any decrease in response time when reading the trained words presented *individually*, suggesting that the treatment may have resulted in some general improvement in the speed of reading *text*, as opposed to individual words. This improvement is not readily interpretable, but may perhaps reflect a general increased confidence with reading. Another unexpected improvement was on auditory comprehension as measured by the BDAE. However, NYR's auditory comprehension score on the Gates-MacGinitie test actually *decreased*, suggesting no general pattern of improvement in her auditory comprehension. Nevertheless, as our data directly comparing performance with and without sentence building showed, strategy-specific improvements in *reading comprehension* and *accuracy* were significantly greater than any general improvements that may have resulted from the treatment.

To what might we attribute the positive effects of repetition priming on the reading performance of this patient? It has been suggested that the effect of repetition priming is to render neural pathways more efficient in the short term processing of specific stimuli (Schacter & Bruckner, 1998). In a recent study that compared the fMRI activation pattern of skill learning (mirror reading) with that of repetition priming, Poldrack and Gabrieli (2001) found evidence of an overlap between the neural mechanisms involved. Areas that showed reduced activation related to skill learning also showed reduced activation related to repetition priming. Reduced fMRI activation has been linked to increased neural efficiency (Schacter & Bruckner, 1998). This improved neural efficiency has been attributed to several possible mechanisms. One explanation of the increased efficiency of neural processing is a lowering of the activation threshold of the particular stimulus (Dean & Young, 1996; McClelland & Rumelhart, 1981; Tulving & Schacter, 1990). In the context of the Sentence Building strategy, once a particular word is presented, the threshold for activating the phonologic representation of that word is lowered for successive presentations. This would translate into a continuous reduction of the activation threshold for phonologic representations with each step of the Sentence Building strategy. Lowered thresholds render phonologic representations more readily accessible and, thereby, can increase reading accuracy.

An alternative interpretation of the decrease in neural activation observed in neuro-imaging studies is that it indicates a switch to a more automatized stimulus-response strategy (Schnyer, Dobbins, Nicholl, Schacter, & Verfaellie, 2006). According to Schnyer and colleagues (2006), this automatized strategy becomes more likely with repetition, and represents a different, more efficient, direct, and associative processing mechanism. For NYR, the Building strategy encourages greater reliance on a more automatized response, rather than an effortful analysis and retrieval process.

A third explanation for reduced neural activation is a sharpening of the neural response to a stimulus (Desimone, 1996; Wiggs & Martin, 1998). With repeated exposure to, or experience with, a specific stimulus, neuronal populations that encode essential features of the particular stimulus remain strongly active, while neuronal populations that encode more generic features, those less critical to stimulus identification, become less active. The result is a net decrease in neuronal activation, and a concomitant increase in efficiency. In terms of Sentence Building, as each step of the building process increases NYR's exposure to the particular words in the sentence, a sharpening of her response to those words occurs.

All of these explanations of increased neural efficiency are consistent with the notion that the underlying cause of PhTA is impaired phonologic activation, and specifically weakened or slowed activation of phonologic representations rather than pathologically rapid decay of phonologic activation, in that repetition priming encourages a faster, more automatic response to a given word.

In sum, the improvement evoked by repetition priming via the use of the Sentence Building strategy can inform our understanding of the neuropsychological basis of PhTA. In addition, theories of the neural underpinnings of repetition priming, e.g. lowering of activation thresholds, increasing automatization of responses, and/or sharpening of neuronal responses, are all consistent with the hypothesis that the repetition priming that is effected through Sentence Building boosts phonologic activation. As NYR 'built' untrained sentences, words of all grammatical classes improved because all words were primed and benefited from strengthened activation. Although Sentence Building did not eliminate NYR's part-of-speech effect, it did sufficiently strengthen phonologic activation, which enabled not only greater oral reading accuracy but reading comprehension as well. As discussed, the success of repetition priming lends support to the view that weakened and/or slowed activation of words in general, and functors in particular, underlies the deficits seen in PhTA.

Due to its tedious nature, Sentence Building has limited functional application for reading lengthy text, such as magazine articles or books. However, with practice, it stands to reason NYR could improve the speed with which she uses the strategy, reducing tedium and increasing utility. The strategy may be particularly applicable to often-used text; in a series of behavioral and computational studies Stark and McClelland (2000) found that repetition priming is greatest when it builds upon current knowledge, as opposed to novelty. Considering the measurable improvement noted in NYR's ability to comprehend text when using Sentence Building, this strategy may serve as a useful tool for reading short, yet vital text, such as cooking or medical instructions and driving directions.

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Figure 1.

T2-weighted MR image of NYR five days post-stroke, left/right reversed, showing infarct of the left MCA, affecting left frontal and posterior temporoparietal regions, including parts of Wernicke's area and thalamus.

Figure 2. Reading Before, During and After Treatment
Graph of sentence reading before, during and after treatment.

Figure 3. Oral Sentence Reading Accuracy

Graph of treatment effect on sentence reading accuracy (both trained and untrained sentences) after 24 treatment sessions.

Figure 4. Reading With and Without the Strategy

Graph of NYR's reading of trained and untrained sentences, using the strategy and not using the strategy.

Figure 5. Comprehension of Untrained Sentences

Graph of NYR's reading comprehension for a separate set of untrained sentences, using the strategy and not using the strategy.

Table 1

Language and cognition assessment

TESTS	Pre-Tx	Post-Tx	Max
Raven's Coloured Progressive Matrices	21	-	36
Test of Nonverbal Intelligence	26 (66%) ^(e)	-	45
Reading Comprehension Battery for Aphasia subtests IV, VI, VII-X	51	52	60
Boston Diagnostic Aphasia Examination			
<u>Auditory Comprehension</u>			
Basic word discrimination	31	35	37
Commands	14	15	15
Complex Ideational Material	6	10	12
<u>Repetition</u>			
Words	8	6	10
Sentences	5	3	10
<u>Naming</u>			
Responsive naming	14	15	20
Boston Naming Test	33	34	60
Special categories	10	12	12
<u>Reading</u>			
Word/Picture match	8	8	10
Oral word reading	29	26	30
Oral sentence reading	3	4	10
Oral Sentence comprehension	3	5	5
Sentence/paragraph	9	4	10
Concreteness/Regularity Single Word Tests			
Abstract	24	28	30
Concrete	22	29	30
Exception words	16	14	30
Regular words	15	14	30
Wechsler Memory Scales: Digit Span			
Forward	5	5	16
Backward	1	3	14

TESTS	Pre-Tx	Post-Tx	Max
Wechsler Memory Scales: Spatial Span			
<i>Forward</i>	7	6	16
<i>Backward</i>	5	5	16
Auditory Word Span			
<i>Concrete nouns</i>	3	-	12
<i>Abstract nouns</i>	1	-	10
<i>Funciors</i>	2	-	12
<i>Pseudowords</i>	0	-	12
<i>Letters</i>	3	-	12
Gray Oral Reading Test (Form A)			
<u>Oral (passages 1,3,5)</u>			
<i>Comprehension</i>	9	12	15
<i>Average syllables/s</i>	0.7	0.89	
<u>Silent (passages 2,4,6)</u>			
<i>Comprehension</i>	10	6	15
<i>Averages syllables/s</i>	1.13	1.38	
Gates-MacGinitie			
<i>Auditory Comprehension</i>	23	18	36
<i>Silent Reading Comprehension</i>	18	17	36
<i>avg. silent reading speed</i>	46s	9.2s	