Published in final edited form as:

Neuropsychologia. 2008 August ; 46(10): 2515–2523. doi:10.1016/j.neuropsychologia.2008.04.004.

A patient with phonologic alexia can learn to read "much" from "mud pies"

Susan Nitzberg Lott¹, Diane M. Sample¹, Robyn T. Oliver^{1,2}, Elizabeth H. Lacey¹, and Rhonda B. Friedman¹

¹Georgetown University Medical Center, Department of Neurology and Center for Aphasia Research and Rehabilitation

²University of Pennsylvania, Department of Psychology (current affiliation)

Abstract

People with phonologic alexia often have difficulty reading functors and verbs, in addition to pseudowords. Friedman et al (2002) reported a successful treatment for phonologic alexia that paired problematic functors and verbs with easily read relays that were homophonous nouns (e.g. "be" paired with "bee"). The current study evaluates the efficacy of pairing problematic grammatical words with relays that share initial phonemes, but vary in the relationship of their final phonemes. Results showed that reading of target grammatical words improved to criterion level (90% accuracy over two consecutive probes) in all experimental conditions with shared phonology, but remained far below criterion level in control conditions. There was a significant correlation between degree of phonologic relatedness and error rate. Maintenance of the treatment effect was poor as assessed by traditional measurement, however a dramatic savings during relearning was demonstrated during a subsequent treatment phase. The finding that reading can be re-organized by pairing target words not only with homophones, but with other phonologically related relays, suggests that this approach could be applied to a wide corpus of words and, therefore, potentially be of great use clinically. We suggest, within a connectionist account, that the treatment effect results from relays priming the initial phonologic units of the targets.

Keywords

aphasia; treatment; maintenance; savings of learning; phonologic priming

Introduction

Phonologic alexia is an acquired reading disorder in which pseudoword reading is impaired relative to real word reading. Additionally, the disorder is often associated with a part-of-speech effect, in which the reading of nouns and adjectives is well preserved, while the reading of functors (grammatical words, such as articles, pronouns, prepositions, conjunctions, etc.), and sometimes verbs, is impaired. This pattern has been attributed to an impaired phonologic

Corresponding author: Susan Nitzberg Lott, Georgetown University Medical Center, Department of Neurology, Building D, Suite 207, 4000 Reservoir Rd., NW, Washington, DC 20057, Phone: 202-784-1764, Email: lotts@georgetown.edu, Fax: 202-687-7378.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

reading route (Friedman, 1996); reading of semantically-rich words remains well preserved through the intact semantic reading route (Glosser and Friedman, 1990).

Impairment of phonologic reading in phonologic alexia has been attributed to impaired grapheme-to-phoneme conversion. Several investigators have designed treatment programs that re-train grapheme-to-phoneme correspondences (GPCs). The results of these treatments are equivocal. dePartz (1986) demonstrated improved reading following a GPC treatment given to a patient with Wernicke's aphasia and deep alexia (a more severe form of phonologic alexia). Each target grapheme was paired with a relay word beginning with that grapheme (e.g. the letter "C" was associated with the name of the subject's wife, "Carole"). The patient was trained to associate the target grapheme with the first phoneme of the relay word. Reading of pseudowords and words was then trained. Oral reading of words improved from 55% to 95% correct, while oral reading of pseudowords improved from 7% to 90% correct. Subsequent treatments modeled after dePartz's, however, were less successful (Laine & Niemi, 1990; Mitchum & Berndt, 1991; Nickels, 1992). The patients in each of these studies re-learned the GPCs but could not blend the phonemes together to successfully read untrained words, despite treatment stages that focused on blending.

Several more recent studies report modified GPC approaches designed to overcome the blending problem. Friedman and Lott (2002) trained bigraph-to-biphone correspondences, instead of individual grapheme-to-phoneme correspondences. That is, rather than training that /b/ + /æ/ + /t/ = bat, they trained two patients to combine /bæ/ and /æt/ into bat. Importantly, both subjects were also able to blend trained bigraphs together so as to read aloud trained words composed of those bigraphs with 90% or greater accuracy. The treatment effect generalized to untrained words that were composed of trained units, but not to those composed of untrained units, supporting the claim that improvement was treatment specific. Kendall et al (1998) implicitly trained pronunciation of the letters "C" and "G" via exposure to multiple, whole word exemplars embodying the grapheme-to-phoneme conversion rules for those letters. Reading of multisyllabic pseudowords beginning with both targets was stable at baseline and showed a dramatic improvement with treatment. It is possible, however, that improvement was not treatment specific, as reading improved on G-words prior to their training, i.e. during C-rule training, and on external reading measures that did not include trained graphemes. Furthermore, there was no report of training or cueing the pronunciation of any letters other than "c" and "g", suggesting that this patient had no difficulty sounding out the other letters.

It has been suggested that phonologic alexia is part of a general phonologic impairment not specific to reading (Cognitive Neuropsychology, 13(6), 1996 special issue on Phonological Dyslexia). Based on this notion, some investigators have trained GPCs within the context of improving overall phonologic awareness. In a single case study reported by Yampolsky and Waters (2002), improved CVC word reading was observed following a treatment program consisting of: GPC training; a phonologic awareness task consisting of manipulating single grapheme cards into various CVC words; tapping a finger for each grapheme; and oral reading of CVCs. No improvement was made reading words of untrained syllabic structures. In another attempt to improve overall phonologic awareness, Kendall et al. (2003) trained two subjects with phonologic alexia to discriminate phonemes based on their visual, auditory and oral kinesthetic distinctive features, and then to use this knowledge to improve reading. Training included tasks to raise awareness of how the articulators move to produce phonemes, and to improve phonemic discrimination within simple (cvc) and complex (ccvcc) pseudowords. Results were equivocal, as one subject demonstrated improved reading, but the other subject did not.

The studies discussed above focus on re-training the impaired phonologic reading route. In a traditional GPC treatment approach, most patients can re-learn grapheme-to-phoneme

correspondences, but many are then unable to blend the phonemes together in order to read words. The modified GPC approaches overcame the blending obstacle, but results were problematic or equivocal: the bigraph treatment, while successful, requires many treatment sessions as there are so many more bigraphs than individual graphemes to train; the whole word approach appears to be applicable only to very mildly impaired patients who retain the ability to sound out most letters. Results from the treatments focusing on overall phonologic awareness were equivocal as some patients improved but others did not. Most importantly, the functional impact of these treatments is not known. Such treatments would not be expected to improve reading of words with irregular spelling-to-sound correspondences, as they specifically train patients to sound words out. It is also not clear whether these treatments improve reading of multisyllabic words. Both of these contexts are extremely relevant to the rehabilitation of people with phonologic alexia, as their main impairment is in reading functor words, which, for the most part, are irregular and/or multisyllabic (e.g. some, of, because, among, etc.). Recent research indicates there may be a more effective approach to rehabilitating people with phonologic alexia than re-training the impaired phonologic reading route.

Some recent studies have focused treatment on the semantic route rather than the phonologic route. Ska et al. (2003) reported a semantically-based treatment for a patient with deep dyslexia who was unable to learn GPCs. JH was trained to associate 50 concrete words with their respective pictures. Training was conducted with index cards containing the written target word on one side and the written target word along with its picture on the other. If unable to read the word, JH was instructed to turn the card over and look at the picture, identify the word, then construct a mental association between the written word and the picture. After 5 sessions, oral reading of trained words improved to 90% correct. There was no improvement reading untrained concrete words (18%), nor on external measures of word fluency and auditory comprehension. At eight months post-treatment, reading of trained words maintained at 84% correct. This study did not include a control task; thus it was not possible to definitively conclude that the specific task used in the treatment was necessary or sufficient for improvement. Furthermore, this particular semantically-based approach could not be applied to people with phonologic alexia; their reading of picturable nouns is intact, and it is precisely their reading of non-picturable words (i.e. functors) that is impaired. Nevertheless, the general notion of invoking the preserved semantic reading route may offer an alternative to trying to restore the phonologic reading route.

Friedman, Sample & Lott (2002) reported a semantically-based approach that focused on re-organizing reading of *non-picturable* words via the semantic reading route. Based on a deep dysgraphia treatment reported by Hatfield (1983), Friedman et al successfully trained two patients with phonologic alexia to read verbs and functors that they were previously unable to read by pairing them with homophonous nouns that they could easily read (e.g. "be" paired with "bee"). The associations between the target and relay words (homophones) were trained via index cards: one side contained the written target word, while the other side contained the homophone in both its written and picture forms along with the written target. The patient was trained to say the homophone, then the target. Both patients succeeded in reading the target words aloud with at least 90% accuracy. Importantly, similar success was not obtained when the treatment consisted of repeated practice reading target words, reinforced with a contextual sentence. This difference between training conditions suggested that success could be attributed to pairing target words with their homophones, and not simply to repeated practice. These results suggested that the reading of certain words could be re-organized by invoking the intact semantic activation of relay words. The phonology of a relay word is accessible because it is supported by rich semantic activation resulting from the relay's orthography, and bolstered by its picture. The phonology of a target grammatical word, however, is not readily accessed because it does not generate sufficient semantic activation to compensate for the impaired phonologic reading route; by definition these words have little semantic value and

are not easily picturable (e.g. “from”, “perhaps”, “really”). Pairing a target with a homophonous relay succeeds because the phonologic activation of the relay primes the phonology of the target.

The requirement that target words must have a homophone, however, clearly limits the set of words that could be trained via Friedman et al’s (2002) paired association treatment. The motivation of the current study, therefore, was to determine whether a larger corpus of words could be successfully trained via this phonologic priming approach even when there was less phonologic similarity between the target and its relay. Based on connectionist models (e.g. Seidenberg and McClelland, 1989; Harm and Seidenberg, 2004; Dell et al, 1997; Plaut, 1996; Welbourn and Lambon Ralph, 2005), in which the activation of one word also results in some activation of other words that have common orthographic, phonologic, or semantic units, we predicted that a relay sharing sufficient phonologic units in common with its target would prime the phonology of that target. We paired target words with relay words that shared initial phonemes, but varied in the relationship of their final phonemes. Our research question was whether pairing target words with relays of these varying degrees of phonologic relatedness would lead to criterion level performance in oral reading of the target words. To test this, we compared post-treatment performance of words trained in phonologically-related experimental conditions to that of words trained in various control conditions. In control training conditions words were trained, but not via phonologically-related relays, in order to test for the general effects of repeated exposure with feedback, as opposed to the specific effects of phonologically-related relays. In addition, there was one untrained control condition, consisting of words that were never trained. We predicted that treatment would be more successful for targets trained via phonologically-related relays than for those trained in the control conditions.

Case History

HN was a 48-year-old woman who suffered a left CVA seven years prior to this study. She had a bachelor's degree and had completed some master's level coursework. She was employed as a government administrator prior to her stroke. Following elective surgery, she sustained a pulmonary embolism that resulted in a left CVA. CT revealed a massive left-sided infarct, compatible with occlusion of the left internal carotid artery, with foci of decreased density within the left frontoparietal region. At that time she reportedly demonstrated a "moderate to severe conduction aphasia characterized by hyperverboecy with decreased self-monitoring, frequent phonemic and some semantic paraphasias, and severely impaired reading and writing."

The Institutional Review Board of Georgetown University Medical Center approved this study, and signed informed consent was obtained prior to assessment and treatment. Upon admission to the current study, she presented with a moderate fluent aphasia as assessed by the Boston Diagnostic Examination of Aphasia (BDAE) (Goodglass & Kaplan, 1983) and the Reading Comprehension Battery for Aphasia (RCBA; Lapointe and Horner, 1984). She demonstrated good verbal expression of automatic sequences and repetition of words and high probability phrases, but poor confrontation naming, responsive naming, animal naming and repetition of low probability phrases. Oral reading of single words and sentences was poor. Reading comprehension of single words was good, but broke down at the sentence and paragraph levels. Auditory comprehension of single words was slow, but well preserved, and comprehension for longer and more complex material was impaired, as was written spelling (see Table 1 and Table 2 for scores).

HN's reading was further evaluated by a battery of reading assessments designed to analyze letter knowledge, oral reading, and spelling. A full description of her reading assessment was

previously reported in Friedman et al 2002. She demonstrated a moderate phonologic alexia characterized by poor pseudoword reading coupled with part-of-speech and concreteness effects, but with no effects of regularity or length. Prior to the current study, she successfully completed the re-organization treatment as reported by Friedman et al (2002). Retesting following that treatment demonstrated persistent difficulty reading pseudowords (0/20 pseudowords and 7/20 words matched to pseudowords. $X^2 = 8.48$, $p < .01$). Because our test for assessing part-of-speech effects contained so many functors that were trained in this initial treatment, she no longer demonstrated a significant difference between concrete nouns and functors; the test contained 13 trained functors of which HN read 10 correctly. She did, however, continue to demonstrate a significant difference between concrete nouns and verbs (26/41 concrete nouns; 13/41 abstract nouns, 16/41 adjectives, 4/41 verbs and 18/41 functors; concrete noun versus verbs $\chi^2 = 23.18$, $p < .001$).

Experiment 1

Method

Stimuli—A list of 279 previously untrained words, primarily functors (174 functors, 60 adverbial functors, 45 -ly adverbs and other affixed words), was presented for single word oral reading during three separate sessions. Functors included articles, prepositions, conjunctions, qualifiers, and post-determiners, while adverbial functors included non -ly adverbs (e.g. thus, always, even) (based on Francis and Kucera, 1982). Treatment stimuli were selected from the words that HN was unable to read correctly on all three sessions. The resulting 120 words were divided into eight lists of 15 predominantly high frequency words each (defined as ≥ 50 based on Francis and Kucera, 1982). Each list contained five one-syllable and ten two-syllable target words that were primarily functors. One list was presented in each of the eight conditions described below.

The eight conditions consisted of four experimental training conditions (targets paired with phonologically-related relays), three control training conditions and one untrained control condition. The four experimental training conditions included pairing targets with the following types of phonologically-related relays: (1) "Near Single Relays": relays are phonologically like the targets at the beginning, but a syllable or part of a syllable must be dropped to arrive at the target (e.g., "bologna" for below); (2) "Near Multiple Relays": relays share all of the attributes of the near single relays but are composed of multiple words (e.g., "four mermaids" for former); (3) "Stretch Single Relays": relays differ from the near single relays in that one must first drop a syllable/part of a syllable and then *add* another syllable or phoneme to arrive at the sound of a target (example: "elk" for "else"); and (4) "Stretch Multiple Relays": relays share all the attributes of stretch single relays but are composed of multiple words (example: "in step" for instead). As discussed earlier, we were interested in whether word pairings with less phonologic similarity than those assessed in Friedman et al's 2002 study could serve as successful relays. We did not attempt to evaluate all types of phonologic relatedness in the experimental conditions. Based on our initial results with homophonous and near homophonous relays, we continued to evaluate phonologically-related relays that shared initial phonemes with their targets; but that were further altered in the relatedness of the ends of the words. The three control training conditions included: (1) "Repetition": no relays; targets are presented for repetition only; (2) "Random 1 Relays": relays have a completely arbitrary relationship to the targets with no semantic relationship or shared initial phonemes; and (3) "Random 2 Relays": same as Random 1 condition but with a different set of words. A fourth control condition consisted of words that were never trained. See Appendix A for stimuli. The RCBA was administered again after treatment as an external measure of reading comprehension.

Design—A single subject, multiple baseline design was used. Treatment was conducted for two one and one-half hour sessions per week. HN was trained to criterion (90% accuracy on two consecutive probe tests) on each condition before moving on to the next condition. Training on any condition was discontinued if performance reached a plateau as defined by the first session in which the slope over the last six sessions went negative (i.e. no improvement over a period of three weeks). Two control training conditions were administered first, Repetition and then Random 1 Relay Words, followed by the four phonologically-related experimental conditions in the order listed above, followed by the third control training condition, Random 2 Relay Words. The second random condition was trained (with a different set of stimuli) following condition six in order to determine if, once the strategy of using a relay word was learned, HN would then be able to use the strategy to improve her reading of the targets. Words from the untrained control condition were never trained, but were tested before, and then again after, treatment was completed.

Procedure

Probe Testing: Each session began with a probe test of the words currently being trained; one of the other training sets was probed once per week on a rotating basis. Probe testing consisted of reading aloud each target presented one at a time in free vision. No cueing or feedback regarding accuracy of individual words was provided. A word was judged by the examiner to be correct only if the exact form of the word was produced (e.g. a response of “usual” for “usually” would be incorrect). All probe responses were recorded on audiotape and periodically judged by a second rater to assess scoring reliability.

Treatment: During training the patient was asked to read aloud each target, which was presented individually on an index card. If read incorrectly, the stimulus card was turned over to reveal written versions of the target and relay along with a picture of the relay. The patient was instructed to name the relay first, and then to pronounce the target. Since the relays were picturable nouns, and were presented in both written and picture forms, it was expected that HN would have little difficulty reading/naming them. If however, she erred in saying the relay, it was presented for repetition. If reading of the target was still unsuccessful after correctly saying the relay, then the target was presented for repetition. In order to maintain equivalent, implicit relationships between the phonology of the targets and their relays across the conditions, HN was never informed of any relationship, or lack thereof, between the paired words. If asked, the experimenter simply replied that some relays might be more helpful than others. HN was given the index cards and instructed to practice them at home in the same manner she did in the session.

Results

The study was conducted over a period of 17 months, which included 69 sessions for the four experimental treatment conditions and 48 sessions for the three control training conditions. HN reached criterion level performance in all four of the experimental conditions in which the targets were phonologically related to their relays. In the three control training conditions, when targets were simply repeated or paired with random relays, HN reached a plateau before criterion was achieved, unable to achieve greater than 44% accuracy (see figure 2 & figure 3). Although there was some improvement in the control training conditions, performance on the final probes of the four experimental conditions was significantly greater than that of the three control training conditions ($15/45$ v $57/60$; $\chi^2 = 42.56$, $p < .001$). Interjudge reliability for scoring the probe tests was 98%.

Data from three¹ of the conditions revealed a pattern suggesting that the closer the phonologic/orthographic relationship between the targets and their relays, the more quickly HN's target reading accuracy reached criterion [More related (Near Single Relays) = 11 sessions; Less

related (Stretch Single Relays) = 14 sessions; Least related (Stretch Multiple Relays) = 18 sessions]. Since this pattern suggested a possible relationship between degree of relatedness and ease of learning, we performed post-hoc analyses to more critically evaluate this relationship. The categories we defined initially controlled for whether or not the entire target phonology was contained within the relay and whether it was contained within one or multiple words; they did not, however, control for the exact amount of “phonemic change” required to derive the target pronunciation from the relay. In order to more specifically assess the degree of phonologic relatedness, we coded each target for the total amount of “phonemic change” from the relay. Phonemic change was defined as the number of phonemes that had to be deleted from the relay, plus the number of phonemes that then had to be added, in order to derive the target pronunciation (e.g. for the target “behind” with the relay “bee hive”, 1 phoneme (/v/) must be deleted from the relay, and then 2 phonemes (/n/ and /d/) must be added to derive the target “behind”, for a total phonemic change of 3). The error rate for each target was calculated by dividing the number of times that word was read incorrectly during probe tests by the total number of probe tests containing that word. Targets were then ranked according to their total amount of phonemic change and error rates. A Spearman rank rho test comparing total phonemic change and error rates yielded a correlation coefficient of .223, which was significant ($p=.044$), suggesting that the amount of phonemic change required to derive the target from its relay was an important factor in how easily the targets were learned.

Because the word sets were trained sequentially, by the end of the entire treatment program between 2 and 12 months had already elapsed since HN had achieved 90% accuracy on the targets trained earlier in the experimental conditions. At this point her overall accuracy on the 60 targets trained in the four experimental conditions was 17% correct. While this is considerably below the criterion level accuracy she had previously achieved, performance was still significantly above her 0% baseline performance (McNemar $p < .0001$). She produced the correct relay for only 5 of the 60 targets. Her reading of the 45 targets trained in the three control training conditions was only 9% accurate; all correct responses were targets contained in the final, most recently trained set (i.e. no targets contained in the two control sets trained at the beginning of treatment were read correctly). She continued to misread all 15 of the untrained control words.

Experiment 2 was conducted in order to determine whether, 1) learning was retained to some degree so that relearning would occur more quickly and 2) additional practice would enable HN to better maintain the large, but diminishing treatment effect on the targets trained in the phonologically-related conditions.

Experiment 2

Method

Stimuli—The 60 targets from the four phonologically-related training sets were re-trained concurrently in one large training set.

Design—Treatment was provided for a single one and one-half hour session per week. Each session began with a probe test of all 60 targets. HN was trained following the same procedure as in Experiment 1 until she again achieved criterion level performance, defined as 90% accuracy on two consecutive probe tests.

¹HN missed several sessions during the Near Multiple Relays condition due to an extended illness. The disruption this caused in her treatment most likely inflated the number of sessions required in this condition, and, therefore, it was excluded from this comparison.

Results

Treatment was conducted for six sessions, drastically fewer than the 69 required to first learn these targets during Experiment 1. Accuracy of the retrained targets returned to 95%. Two weeks after retraining, accuracy remained high at 63% correct, significantly greater than before retraining (McNemar $p < .0001$). She produced the correct relay for 30 of the 60 retrained targets. Three and a half months after retraining, HN was 20% accurate on the retrained targets, still significantly above baseline level performance (McNemar $p < .0001$). At this time she produced the correct relay for only three of the 60 retrained targets.

The RCBA was re-administered following Experiment 2 in order to assess any generalization to reading comprehension. Scores remained essentially the same, with the exception of minor improvement on the paragraph-picture subtest (see Table 2).

Discussion

The results show that it is possible to improve oral reading in phonologic alexia by pairing problematic words not just with their homophones, but with other phonologically related words, or strings of words. The results further suggest that improvement in word reading was treatment specific. Spontaneous improvement was not a likely factor as HN was seven years post onset at the beginning of this study, improvement on each set of targets did not begin until each set was specifically trained, and improvement did not occur on matched, untrained words. Although HN did demonstrate some improvement on the targets trained in the control conditions, she could only achieve criterion level performance when the relays were phonologically related to the targets; she was not nearly as successful when the targets were simply practiced repeatedly with feedback or paired with unrelated relays, nor was she able to learn to self-cue by independently finding successful relays.

Clinical Implications

This expanded paired association approach has important clinical implications. Because reading improved via pairings between words of varying degrees of phonologic similarity, this approach may be used for virtually any problematic word. The corpus of possible training words is not limited to words that only have direct or near homophones. Any word can be trained as long as it can be paired with a word, or words, with the same initial phonemes, regardless of the relationship of the final phonemes. Fewer errors were made when the target and the relay were more closely related phonologically. The correlation between these two variables, however, was relatively small and many other factors may affect successful association of a given pair of words (e.g. orthographic, semantic, and syntactic). Clearly, further study is needed to determine which of these other parameters are also relevant to the efficacy of this treatment.

Clinical treatment often focuses on comprehension rather than oral reading of single words. This, however, is the paradox of treating phonologic alexia. The very words that people with phonologic alexia have difficulty reading are words with little meaning of their own, i.e. functor words. Indeed, the reason these words are problematic is that they are not well represented semantically (Glosser & Friedman, 1990). If a functor word does not have much meaning, how, then, does one demonstrate improved understanding of it? Word-picture matching is not an obvious choice for words such as “of”. Functors take on their meaning when they are contained within a sentence. Sentence reading, however, requires many other abilities, such as verbal working memory and syntax comprehension. Since these other abilities are not addressed in this paired associate treatment, impairment in these domains could preclude any improvement in sentence comprehension. Indeed, HN demonstrated reduced verbal working memory as measured by a pseudoword repetition test containing 1, 3 and 5 syllable

pseudowords (14/30) and reduced syntax comprehension as measured by RCBA Morpho-Syntax subtest (3/10). It is not unexpected, therefore, that she was unable to demonstrate meaningful improvement in reading comprehension on the RCBA. Nevertheless, since functor words are difficult to remediate via traditional grapheme-to-phoneme conversion treatments (because of their irregularity or the difficulty in blending phonemes, as previously discussed), paired associate treatment represents an important first step in remediating these words that have been shown to be difficult to retrain.

Following Experiment 2, HN demonstrated maintenance that was superior to that after Experiment 1. This supports the notion that extending practice beyond the time when criterion is first achieved may be important for long term maintenance (McNeil et al, 1998). Because phonologically-related relay treatment yielded better initial results than non phonologically-related treatment (90% versus 44%), this improved maintenance following extended learning suggests that the relay treatment has more potential than simple drilling (i.e. repetition condition) to yield a positive functional outcome. However, although maintenance was greater following this extended learning, this benefit was greatly reduced by three and a half months post relearning. While reports on the maintenance of treatment effects are becoming more common in aphasia treatment studies, a review of the primary research treatment papers published during 2006 in *Aphasiology* revealed that most studies did *not* assess maintenance of treatment effects for a period longer than four to six weeks post-treatment, and no study assessed maintenance for a period longer than three months. Studies of long-term maintenance of treatment effects are clearly needed.

Theoretical Implications

Theoretically, these findings have interesting implications as well. Friedman et al (2002) suggested that such re-organization of reading was the result of pairing items within the same levels of representation. That is, a *written* target and its *written* relay, two items at the same level of representation (orthographic), are paired. The intact reading of the relay, via the semantic reading route, allows for processing to continue from one level of representation (orthographic) to another level (phonologic). The *pronunciation* of the relay is then successfully paired with the *pronunciation* of the target, again because they are both at the same level of representation (phonologic). According to the model, if the patient can successfully learn the paired association between the target and its relay, then oral reading improves because the phonology of the target is primed by the shared phonology of the relay.

In the current study, however, reading of targets improved even when the relays shared only *initial* phonemes (e.g. target *else* with the relay “elk”). How does the model account for success when word pairs are only partially related phonologically, as in the current study? In connectionist models, words are represented as patterns of activated connections between orthographic, phonologic, and semantic units (e.g. Seidenberg and McClelland, 1989; Harm and Seidenberg, 2004; Dell et al, 1997; Plaut, 1996; Welbourn and Lambon Ralph, 2005). In these models when a word is activated, words with common units receive some activation as well. It is plausible, then, that activation of the common units by the relay could provide sufficient priming of the phonology of the target. There is evidence that phonologic priming boosts word retrieval in normal, older adults when the primes consist of homophones as well as words sharing only the initial syllable. Burke et al (2004) showed that normal elderly participants improved their naming of famous people when trials were preceded by production of a homophonous prime but not when preceded by a non-homophonous prime. Successful priming of word retrieval in normal elderly has also been shown with words that share only the first syllable (White and Abrams, 2002). In this study, participants were asked to answer general knowledge questions to which they responded whether they knew or did not know the answer, or whether it was on the tip-of-the-tongue (TOT). They then read a list of priming

words that contained seven unrelated words and three experimental words. The experimental words shared either the first, middle, or final syllable and the unrelated words shared no syllable with the target. Both the 18–26 year old and 60–72 years old groups resolved more TOTs following priming word lists containing words sharing first syllables than by lists containing any other words. The authors claim that word finding errors in normal elderly TOT states are the result of weakened connections between lexical and phonologic units. They suggested that activation of the shared initial syllable nodes in the phonologic system resulting from the primes sharing first syllables with the target was sufficient to compensate for those weakened connections and allow a greater number of resolved TOT states. We suggest that a similar mechanism may account for the success of the phonologically related relays in the current study. That is, poor functor reading is the result of weakened connections between orthography and phonology. When the relay's phonology is activated prior to reading the target, that activation sufficiently primes the initial phonemes of the target. This priming sufficiently boosts phonologic activation levels to allow correct target word reading.

In phonologic alexia, orthography-to-phonology connections are impaired such that phonologic representations can only reach subthreshold activation levels via this route. The summation of this weakened activation plus activation from semantics may be sufficient to reach threshold levels if the word is rich in semantic content (e.g. relay “shark” in Figure 4a). Words that are not rich in semantic content do not generate sufficient semantic activation to achieve threshold level phonologic activation (e.g. target “until” in Figure 4a). To expand upon the model discussed above that was originally proposed for the paired association treatment (Friedman et al, 2002), words are first paired at the orthographic level, when a written target is paired with a written relay. If the relay does not share initial phonology with the target (e.g. random relay), then no phonologic priming occurs (see Figure 4a). On the other hand, if the relay and the target do share initial phonemes, then activation of the relay's phonology primes the target's phonology (see Figures 4b and c). Because activation flows bidirectionally, activation of the shared phonemes achieved by the relay flows back to the phonologic representation of the target, thereby priming the target's pronunciation. The target's phonologic representation reaches threshold via a summation of partial activation from this bidirectional flow and from the partial activation achieved through the target's weakened orthography to phonology connections. Activation reverberates throughout the network such that all phonemes of the target achieve threshold. As the significant correlation between number of errors and amount of phonemic change suggests, when the total number of discrepant phonemes activated by the target and its relay is low (e.g. homophone relay as in Figure 4b), fewer errors are likely to be made producing the target than when the number of activated discrepant phonemes is relatively high (e.g. single stretch relay as in Figure 4c). This difference is likely due to inhibition and/or reduced priming resulting from the discrepant phonemes.

HN did demonstrate moderate improvement reading words trained in the non-phonologically related control conditions (plateau at 44%). This improvement was likely due to the effects of repeated exposure with feedback. Her improvement reading words trained in the phonologically-related conditions (90%), however, was significantly greater than that of words trained in non-phonologically-related conditions. This significant difference likely reflects the effects of phonologic priming over and above any effects from repeated exposure with feedback.

Since phonologic priming occurs when the target is preceded by a prime word with shared initial phonology, it is therefore necessary to access the relay before producing the target. This may explain HN's reduced ability to maintain the treatment effect. It is possible that HN simply forgot many of the explicit paired associations between the targets and their relays after treatment ended and, therefore, was unable to prime the phonology of the target response. To empirically test this hypothesis, we could have asked the patient to state the relay after each

trial to determine whether or not she had forgotten them. However, asking for the relays would likely cue her to think of the relays in subsequent trials, and therefore testing would no longer be conducted under baseline conditions. HN's spontaneous, overt responses during post testing, however, were consistent with the hypothesis that she failed to produce the target because she forgot the relay. Post- Experiment 1, when accuracy was poor (17%), she spontaneously produced the correct relay on only 8% of the trials. Post-Experiment 2, when accuracy was high (63%) she spontaneously produced the correct relay on 50% of the trials. At Follow-Up testing, when accuracy was again poor (20%), she spontaneously produced the correct relay on only 5% of the trials. Also consistent with the hypothesis that HN failed to produce the target because she forgot the relay, is that HN was observed producing errors after trying, but failing, to get the correct relay. Examples included: 1) a monkey (amongst): "it's a, not a bunny rabbit, chimpanzee, not a chimpanzee" and 2) Amtrak (am): "I know it, inside, they're on a locomotive and they're riding along".

HN's performance during Experiment 2 further supports the hypothesis that her reduced performance on follow-up testing was the result of poor explicit recall. In Experiment 1, HN required 69 sessions to learn the 60 words to criterion, whereas in Experiment 2, she required only six. Had she truly "lost" most of what she had learned in Experiment 1, she could not have relearned the items ten times more quickly in Experiment 2. This effect, called savings during relearning, was first articulated by Ebbinghaus (1885/1964) and later discussed by Nelson (1985, 1978). This measure of retention during relearning is unique in that, unlike traditional follow-up testing that relies on "conscious" memory, it reveals information that is retained but not "consciously" accessible. Any information that is remembered after treatment, be it conscious or unconscious, is important for cognitive rehabilitation.

Acknowledgements

This research was supported by NIH grants HD036019 and DC01799 to the last author. Robyn Oliver contributed to this research during her affiliation with Georgetown University Medical Center. The authors would like to thank HN for her dedication to this project.

References

- Burke DM, Locantore JK, Austin AA, Chae B. Cherry pit primes Brad Pitt: Homophone priming effects on young and older adults' production of proper names. *Psychological Science* 2004;15(3):164–170. [PubMed: 15016287]
- Dell GS, Schwartz MF, Martin N, Saffran EM, Gagnon DA. Lexical access in aphasic and nonaphasic speakers. *Psychological Review* 1997;104(4):801–838. [PubMed: 9337631]
- dePartz M-P. Re-education of a deep dyslexic patient: Rationale of the method and results. *Cognitive Neuropsychology* 1986;3(2):149–177.
- Ebbinghaus, HE. *Memory: A contribution to experimental psychology*. New York: Dover; 1964. Original work published 1885; translated 1913
- Francis, WN.; Kucera, H. *Frequency analysis of English usage: Lexicon and grammar*. Boston: Houghton Mifflin Company; 1982.
- Friedman RB. Recovery from deep alexia to phonological alexia: points on a continuum. *Brain and Language* 1996;52:114–128. [PubMed: 8741978]
- Friedman RB, Sample DM, Lott SN. The role of level of representation in the use of paired associate learning for rehabilitation of alexia. *Neuropsychologia* 2002;40:223–234. [PubMed: 11640944]
- Friedman RB, Lott SN. Successful blending in a phonologic reading treatment for deep alexia. *Aphasiology* 2002;16(3):355–372.
- Glosser G, Friedman RB. The continuum of deep/phonological alexia. *Cortex* 1990;26:343–359. [PubMed: 2249436]
- Goodglass, H.; Kaplan, E. *The assessment of aphasia and related disorders*. 2nd edition. Philadelphia: Lea and Febiger; 1983.

- Harm MW, Seidenberg MS. Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review*, Jul 2004;111(3):662–720.
- Hatfield, FM. Aspects of acquired dysgraphia and implications for re-education. In: Code, C.; Muller, DJ., editors. *Aphasia therapy*. London: Edward Arnold; 1983.
- Kendall DL, Conway T, Rosenbek J, Gonzalez-Rothi L. Phonological rehabilitation of acquired phonologic alexia. *Aphasiology* 2003;17(11):1073–1095.
- Kendall DL, McNeil MR, Small SL. Rule-based treatment for acquired phonological dyslexia. *Aphasiology* 1998;12(78):587–600.
- Laine, M.; Niemi, J. Can the oral reading skills be rehabilitated in deep dyslexia?. In: Hietanen, M.; Vilkki, J.; Niemi, M-L.; Korkman, M., editors. *Clinical Neuropsychology: Excursions into the field in Finland* (80–85). Suomen Psykologinen Seura; 1990.
- LaPointe, LL.; Horner, J. *Reading Comprehension Battery For Aphasia*. Tigard, Or.: CC Publications, Inc.; 1984.
- McNeil MR, Doyle PJ, Spencer K, Jackson Goda A, Flores D, Small SL. Effects of training multiple form classes on acquisition, generalization and maintenance of word retrieval in a single subject. *Aphasiology* 1998;12:575–585.
- Mitchum CC, Berndt RS. Diagnosis and treatment of the non-lexical route in acquired dyslexia: an illustration of the cognitive neuropsychological approach. *Journal of Neurolinguistics* 1991;6(2): 103–137.
- Nelson TO. Ebbinghaus's contribution to the measurement of retention: Savings During Relearning. *Journal of Experimental Psychology: Learning, Memory and Cognition* 1985;11(3):471–479.
- Nelson TO. Detecting small amounts of information in memory: Savings for nonrecognized items. *Journal of Experimental Psychology: Human Learning and Memory* 1978;4(5):453–468.
- Nickels L. The Autocue? Self-generated phonemic cues in the treatment of a disorder of reading and naming. *Cognitive Neuropsychology* 1992;9:155–182.
- Plaut DC. Relearning after damage in connectionist networks: Toward a theory of rehabilitation. *Brain and Language* 1996;52:25–82. [PubMed: 8741976]
- Seidenberg MS, McClelland JL. A distributed, developmental model of word recognition and naming. *Psychological Review* 1989;96(4):523–568. [PubMed: 2798649]
- Ska B, Garneau-Beaumont G, Chesneau S, Damien B. Diagnosis and rehabilitation attempt of a patient with acquired deep dyslexia. *Brain and Cognition* 2003;53:359–363. [PubMed: 14607181]
- Welbourne SR, Lambon Ralph MA. Using computational, parallel distributed processing networks to model rehabilitation in patients with acquired dyslexia: An initial investigation. *Aphasiology* 2005;19(9):789–906.
- White KK, Abrams L. Does priming specific syllables during tip-of-the-tongue states facilitate word retrieval in older adults? *Psychology and Aging* 2002;17(2):226–235. [PubMed: 12061408]
- Yampolsky S, Waters G. Treatment of single word oral reading in an individual with deep dyslexia. *Aphasiology* 2002;16(456):455–471.

Figure 1.

Example of a training card. The written target word is presented in isolation on the front of the card (left); on the back of the card the target is underlined and paired with a relay in both its written and pictorial forms (right).

Figure 2.

HN's target word reading accuracy before, during and after training in each condition. For Experiment 1 and Experiment 2, A represents periods of no training; B represents periods of training.

Note: After session #14 in the near multiple relay condition, HN became ill and, therefore, was able to attend only two sessions in a one month period. HN's performance reached plateau after session #16, but training in this condition was continued because of the disruption in her treatment. B2 represents the period of training after her return.

Figure 3. HN's target word reading accuracy immediately after each condition was trained. Criterion level performance was achieved in all four experimental conditions (black), but not in the control conditions (gray).

Figure 4.
a–c. A general connectionist model of phonologic priming in the paired association treatment in the case of a) a random relay (no priming) b) a homophone relay (complete priming) and c) a single stretch relay (partial priming). Components are symbolized as follows: orthography (Δ); semantics ($\square$); word phonology ($\circ$); phonemes ($\circ$; $\bullet$ shared); connections ($-$ intact; $\cdots$ weakened); oral reading response ($\hookrightarrow$); and insufficient activation is outlined in gray.

Table 1

Diagnostic scores from Boston Diagnostic Aphasia Exam (BDAE) at seven years post-onset.

BDAE subtest	Raw Score
Word Discrimination	49/72
Body Part Identification	11.5/20
Commands	7/15
Complex Ideational Material	7/12
Automatized Sequences	8/8
Repetition of Words	8/10
Repeating Phrases - high probability	5/8
Repeating Phrases - low probability	1/8
Word Reading	14/30
Responsive Naming	20/30
Visual Confrontation Naming	53/114
Animal Naming	5/min
Oral Sentence Reading	1/10
Symbol and Word Discrimination	9/10
Word Recognition	5/8
Comprehension of Oral Spelling	1/8
Word-Picture Match	8/10
Reading Sentences and Paragraphs	4/10
Serial Writing	29/47
Primer Level Dictation	6/15
Spelling to Dictation	0/10
Written Confrontation Naming	0/10
Sentences Written to Dictation	---

Table 2

Pre and Post Treatment scores on Reading Comprehension Battery for Aphasia (RCBA)

RCBA subtest	Raw Score Before Treatment (7 years post-onset)	Raw Score After Treatment (9 years post-onset)
Functional reading	5/10	5/10
Sentence-picture	9/10	10/10
Paragraph-picture	1/10	4/10
Morpho-Syntax	3/10	1/10
Paragraph	10/20	11/20

Target words and their respective relay words for the control and experimental conditions (Untrained and Repetition conditions did not include relay words).

APPENDIX A			
Untrained		Repetition	
Random Relays 1		Random Relays 2	
Target	Relay	Target	Relay
again	brain	aren't	airplane
how's	film	beneath	coffee maker
hearer	fountain pen	cannot	cow
now	jog	couldn't	escalator
ourselves	knight	despite	frying pan
ownself	knit	nothing	heart
someone	lawn mower	quite	hug
something	light bulb	the	ice cream cone
somewhere	mortar and pestle	themselves	kettle
that's	nail clippers	this	old man
they're	oh no	when	paper clip
wasn't	sewing machine	within	paper towels
weren't	shark	yet	polishing nails
youngest	staircase	yourself	a tree in the forest
you've	leaf	yourselves	video game
Near Multiple Relays			
Target	Relay	Target	Relay
am	Amtrak	almost	almond
apart	apartment	any	entrance
away	awake	clearer	clearance
below	bologna	either	ceek
even	evening	else	elk
ever	Everest	from	front
he	heat	gravest	gravestone
how'd	howdy	himself	hymnbook
into	intuition	like	lime
I've	ivy	midway	midwife
many	miniskirt	mustn't	muscle
no	note	she'd	sheet
over	ovary	toward	torn
really	reeling	was	wonder
unto	untutored	wouldn't	woodchuck
Stretch Multiple Relays			
Target	Relay	Target	Relay
am	Amtrak	although	all the king's men
apart	apartment	amongst	a monkey
away	awake	backward	back woods
below	bologna	behind	bee hive
even	evening	each	Easter bunny
ever	Everest	further	fur coat
he	heat	halfway	half n half
how'd	howdy	indeed	Indy 500
into	intuition	instead	in step
I've	ivy	less	left wing
many	miniskirt	much	mud pies
no	note	onward	on with the show
over	ovary	perhaps	per hour
really	reeling	plus	plug in
unto	untutored	same	St. Patrick's Day