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The nature and treatment of phonological text agraphia

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Abstract

Phonological alexia and agraphia are written language disorders characterised by disproportionate difficulty reading and spelling nonwords in comparison to real words. In phonological alexia, it has been shown that, despite relatively accurate reading of words in isolation, text-level reading deficits are often marked and persistent. Specifically, some individuals demonstrate difficulty reading functors and affixes in sentences, a profile referred to as phonological text alexia. In this paper, we demonstrate an analogous manifestation of the phonological impairment on text-level writing and suggest the term “phonological text agraphia”. We examined four individuals with phonological alexia/agraphia who also showed disproportionate difficulty writing well-formed sentences in comparison to their grammatical competence in spoken utterances. Implementation of a phonological treatment protocol resulted in significantly improved sublexical phonology skills as well as improvements in grammatical accuracy of written narratives. These findings support the notion of a common phonological impairment underlying nonword reading/spelling deficits and sentence-level difficulties.

Keywords

Agraphia; alexia; aphasia; phonological text alexia; writing; spelling

Introduction

Phonological alexia and agraphia are written language disorders characterised by marked difficulty reading and spelling nonwords relative to real words (Beauvois & Dérouesné, 1979; Shallice, 1981). Although early descriptions of the syndromes suggested that the underlying deficit was specific to written language processing attributable to the break-down of sublexical phoneme-grapheme conversion (Beauvois & Dérouesné, 1979; Patterson,

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1982; Warrington & Shallice, 1980), there is considerable evidence from recent research favouring a more general impairment of central phonological processing skills (Crisp & Lambon Ralph, 2006; Fiez, Tranel, Seager-Frerichs, & Damasio, 2006; Patterson & Marcel, 1992; Rapcsak et al., 2009). Consistent with the phonological deficit hypothesis, phonological difficulties are typically evident not only in reading and spelling but also on non-orthographic tasks that require manipulation of sounds, such as deleting or replacing a phoneme in a word/syllable or blending a sequence of individual sounds into a syllable or word. Limited explicit access to sublexical phonological information would be expected to interfere with the ability to transcode from letters to sounds (in reading) and sounds to letters (in writing) (Berndt, Haendiges, Mitchum, & Wayland, 1996; Henry, Beeson, Stark, & Rapcsak, 2007; Patterson & Marcel, 1992; Rapcsak et al., 2009; Shallice, 1981). The phonological impairment interferes with the ability to process unfamiliar words (and pseudowords/nonwords that are often used for assessment) by the sublexical pathway, but relatively preserved lexical-semantic abilities provide support for the recognition and retrieval of orthographic forms for familiar words in reading and spelling. This differential performance in favour of real words over pseudowords yields a marked lexicality effect, the hallmark feature of phonological alexia and agraphia (Beauvois & Dérouesné, 1979; Rapcsak et al., 2009; Shallice, 1981). In addition to these behavioural observations, the phonological deficit hypothesis of phonological alexia/agraphia is also supported by lesion-deficit correlation studies that have demonstrated a strong association between these written language disorders and damage to left perisylvian cortical networks implicated in phonological processing (for review, see Rapcsak & Beeson, 2015; Rapcsak et al., 2009).

Although the central feature of phonological alexia and agraphia is the marked difficulty with pseudowords in relation to real words, reading and spelling performance for words is not always at ceiling. Response accuracy for real words is often influenced by lexical-semantic variables, such as word frequency (high > low) and imageability (concrete > abstract), and patients often have disproportionate difficulty processing grammatical morphemes (Crisp & Lambon Ralph, 2006; Roeltgen, Sevush, & Heilman, 1983; Shallice, 1981; Shallice & Warrington, 1975). Limited access or impaired selection of closed class vocabulary items/grammatical markers is typically manifested by omission or substitutions of functors and affixes in reading and spelling. These effects have been interpreted to reflect excessive reliance on lexical-semantic mechanisms in written language processing without support from the sublexical pathway for phoneme-grapheme conversion (Crisp & Lambon Ralph, 2006; Rapcsak & Beeson, 2015). In particular, it is assumed that sublexical support is normally required for reading/spelling items that are relatively unfamiliar and/or have sparse semantic representations (e.g., low frequency words, abstract words, functors and bound morphemes) and therefore cannot be handled efficiently by the lexical-semantic pathway¹. Importantly, there is evidence that the nonword and real word reading/spelling impairments are both correlated with and predicted by the severity of the underlying phonological impairment (Crisp & Lambon Ralph, 2006; Rapcsak et al., 2009).

¹The integrity of the sublexical pathway is also required to eliminate potential semantic errors arising from exclusive reliance on the lexical-semantic procedure for reading and spelling. Although patients who produced semantic errors were previously classified as “deep” rather than phonological alexia/agraphia, there is much evidence that the difference between these written language disorders are quantitative rather than qualitative. Acknowledging this overlap, we use the term phonological agraphia to refer to both entities in this paper.

In addition to the difficulty processing items with impoverished semantic representations in single word reading/spelling tasks, there is evidence that impaired access to closed class vocabulary items may be substantially exacerbated by tasks that require sentence-level processing. Friedman (1996) called attention to the significant impairment in text-level reading in a case description of two individuals with phonological alexia. Despite relatively good single-word reading, oral reading of written text was marred by errors in functors (e.g., determiners and prepositions), as well as incorrect or missing inflectional or derivational markers. Friedman (1996) dubbed this profile “phonological text alexia”. In addressing why oral reading of functors and affixed words was specifically impaired at the sentence level, Friedman proposed that the processing deficit was related to the inability to hold multiple phonological codes in verbal short-term memory, and suggested, “If the phonological code cannot be properly maintained, words with strong semantic value may benefit by receiving reactivation from their semantic representations” (p. 882). Thus, words with reduced semantic weight, such as functors, were prone to error, as they “would not be the beneficiaries of such activation boosts” (p. 882). Friedman confirmed that the nature of the problem was not in verbal production, nor was there impairment in grammatical knowledge, even though grammatical errors were prominent in oral reading. Thus, it appears that sentence-level written language processing places additional demands on phonology relative to self-generated spoken utterances.

Text-level writing skills have received limited attention in individuals with phonological agraphia, but in his seminal paper describing the syndrome, Shallice (1981) noted that attempts to write at the paragraph level were markedly disturbed and writing errors included “omission of verbs, incorrect conjugation of verbs, and function word substitutions” (p. 416). These features are analogous to the reading errors that characterise phonological text alexia. Similarly, Bub and Kertesz (1982) noted impairment of sentence-level writing in their case report of an individual with phonological agraphia (MH). They indicated, “written output is characterised by correct choice of content words but with very poor control over function words, verbs and morphemes” (p. 708). The discrepancy between single word and text writing was especially striking, as MH could spell functors accurately to dictation. Additional insight into the nature of MH’s difficulty in writing sentences was offered by her comment, “I can only get one thing at a time and I’m trying so hard to get the big words, I can’t get the little ones” (p. 710). This utterance also demonstrates the relatively good syntactic structure of MH’s spoken language, which was fluent but highly anomie. Bub and Kertesz (1982) suggested about MH’s profile, “This inability to use an apparently intact grasp of syntax in the written output modality points to a possible limitation in the lexical writing system, which, although capable of good performance at the single word level, seems to break down when sequencing of words in grammatically coherent structures is required” (p. 710). They further suggested that MH’s “poor sentence writing may point to the importance of phonology in sustaining output at the syntactic rather than the single word level” (p. 710).

Despite these early observations, the nature of the text-level writing impairment and its relationship to the underlying phonological deficit has not been carefully scrutinised in individuals with phonological agraphia. In this paper, we present four individuals who had left perisylvian damage that resulted in aphasia with concomitant phonological alexia and

agraphia. They all complained of difficulty writing for everyday needs, and writing samples showed marked impairment of grammatical construction compared to better preserved (or recovered) grammar in their spoken utterances. Similar to the patient presented by Bub and Kertesz (1982), they all demonstrated better syntactic structure of spoken utterances compared to written sentences. Each participant received behavioural treatment intended to strengthen phonological skills and to promote the use of phonology to improve single-word spelling. It ultimately became apparent that these cases demonstrated a common pattern of written language impairment that is analogous to “phonological text alexia” described by Friedman (1996). We present their behavioural profiles and propose the term “phonological text agraphia” to refer to this sentence-level writing impairment. In addition, we document the finding that grammatical construction of written sentences improved after treatment directed towards phonological processing skills, and consider the role that phonology plays in the ability to write grammatically correct sentences.

Methods

Participants

Four individuals with left perisylvian damage due to middle cerebral artery stroke were examined as part of a larger treatment study to address acquired impairments of language. They ranged in time post-onset from 4 months to 10 years (see Table 1). All four participants confirmed that they had average or better spoken and written language skills prior to their strokes. Audiometric testing (pure-tone air-conduction thresholds) showed each participant’s hearing was within normal limits, and they were able to repeat real single words with little to no difficulty. As detailed below, their performances on the Western Aphasia Battery (WAB; Kertesz, 1982) and the Boston Naming Test, Second Edition (BNT; Kaplan, Goodglass, & Weintraub, 2001) indicated a common profile of anomic aphasia at the time of this study. They had no complaints regarding nonverbal cognitive skills, which was consistent with their preserved nonverbal problem-solving abilities as measured by Raven’s Colored Progressive Matrices (Raven, 1977; see Table 1).

The location and extent of left hemisphere damage was determined for each individual by the acquisition and analysis of high-resolution magnetic resonance image (MRI) brain scans using the procedures described in Andersen, Rapcsak, and Beeson (2010). Lesions are depicted on standard brain templates in the sagittal plane in Figure 1. Total lesion volume varied across participants (Table 1) but all had damage that included the perisylvian language zone (i.e., affecting posterior inferior frontal gyrus, supramarginal gyrus, or superior temporal gyrus).

Participant 1HT was a 52-year-old female with 18 years of education. At 10 years post-stroke, she exhibited mild anomic aphasia on the WAB (AQ 93.8) but her clinical history suggested that this profile had evolved from Broca’s aphasia. As shown in Figure 1(a), she had a large lesion affecting primarily the left frontal regions. She complained at the time of evaluation, “I just can’t write,” referring to difficulty writing simple correspondences such as thank you notes. She stated that her reading abilities were “pretty good” and not an area of concern.

Participant 2JW was a 52-year-old male with a high school education. He was 4 months post-stroke at the time of his initial evaluation. A left middle cerebral artery stroke had damaged the posterior inferior frontal cortex and extended to the ventral parietal lobe, see Figure 1(b). His spoken language performance on the WAB indicated a mild–moderate anomic aphasia, with a mild naming impairment on the BNT (50/60). He had not returned to his job in sales, and his concerns about written language included considerable difficulty composing email messages and creating lessons for an adult Sunday school class that he facilitated.

Participant 3GG was a 37-year-old male with 15 years of education. At 4 months post-stroke, his anomic aphasia was relatively mild as indicated by his performance on the BNT (51/60). His lesion, see Figure 1(c), affected the perisylvian frontal and parietal regions. He had been working in sales and attending seminary classes at the time of his stroke. He indicated that he was not yet able to return to those pursuits, primarily because of his difficulties with reading and writing.

Participant 4RL was a 78-year-old male with 20 years of education. He was seen for initial evaluation 2.5 years following a stroke that had affected the left inferior parietal cortex, including the supramarginal gyrus, see Figure 1(d). His spoken language profile was consistent with anomic aphasia, and his lexical retrieval difficulty was slightly more prominent than the other participants (40/60 correct on the BNT). He was a retired lawyer who continued to do some consulting work, but complained that he had considerable difficulty with written correspondence and reports. He did not express concerns regarding his reading abilities.

Comprehensive language and cognitive assessment

A comprehensive assessment was administered to further examine language skills and the status of central linguistic domains (semantics, phonology, orthography), as well as relevant visual and sensorimotor skills. The assessment tasks provided a means to identify deficits and preserved skills, and to generate composite scores to characterise performance in the areas of interest. Individual scores were evaluated relative to a group of healthy adults with no history of brain damage, cognitive problems, or language difficulties, using Crawford and Howell's (1998) modified *t*-test. For most tasks, data were available from 32 control subjects (11 males; 21 females), who had a mean age of 63.9 years ($SD = 10.7$). The assessment tasks are described below for each domain (see Appendix A for individual tasks that contribute to the composite scores).

Semantic processing

Five measures of semantic knowledge were administered: the picture and written versions of the Pyramids and Palm Trees Test (Howard & Patterson, 1992), the spoken word-to-picture matching and written word-to-picture matching tasks from the Psycholinguistic Assessment of Language Processing in Aphasia (PALPA Subtests 47 and 48; Kay, Lesser, & Coltheart, 1992), and an auditory synonym judgement task (PALPA 49). A semantic composite score was calculated that reflected performance on each of the five measures with equal weighting.

Phonological processing

Phonological abilities were examined using tasks across increasing levels of difficulty. Auditory speech perception was probed using a minimal pair judgement task (40 item-pairs taken from PALPA 1 and 2) and a rhyme judgement task (40 items taken from PALPA 15). This was complemented by spoken repetition of the 20 nonwords from the Arizona Battery for Reading and Spelling (ABRS; see Beeson, Rising, Kim, & Rapcsak, 2010) and 20 real words from the ABRS matched in length to the nonwords. The digits forward subtest from the Wechsler Memory Scale–Revised (1987) was administered to provide an index of verbal short-term memory. An analogous auditory span task was also administered that required pointing to a sequence of spoken digits without a verbal response. Phonology-orthography transcoding skills were assessed with tasks that required participants to convert orthography to phonology and vice versa, including the production of letter-sound/sound-letter correspondences for single consonants and reading/spelling of consonant-vowel-consonant (CVC) nonwords. The average performance on those tasks yielded a phonology-orthography transcoding composite score. More complex phonological processing was assessed using tasks that required the identification, maintenance, and manipulation of sublexical phonology, specifically, those tasks involved phoneme segmentation, deletion, blending, and replacement. For the purpose of comparison with other cognitive processes, performance across the three sets of tasks (phonological perception/production, phonology/orthography transcoding, and phonological manipulation) was averaged to generate a single phonological processing composite score (Table 1).

Visual and sensorimotor skills

The ability to visually process individual letters and words was assessed using six subtests from the PALPA including mirror-reversed letters (PALPA 18), matching upper- to lower-case letters (PALPA 19, 20), and lexical decision tasks (PALPA 24, 25, 27). Graphomotor control for writing was examined on a direct copying task using a standard set of common words, and allographic knowledge was assessed using case conversion tasks (i.e., converting from lower to upper case, and vice versa). These measures were summarised with composite scores for visual-orthographic processing and allographic and graphomotor skills, respectively.

Reading and spelling

Single-word reading and spelling abilities were examined using the 100 items (80 words and 20 pseudowords) from the Arizona Battery for Reading and Spelling. The words ranged in length from 4 to 7 letters ($M = 5.1$, $SD = .92$), and the nonwords were comparable in length ($M = 4.95$; $SD = .74$). A lexicality effect was calculated that reflected the difference in the accuracy (percent correct) between real words and nonwords on the reading and spelling tasks. Reading accuracy for single words was also examined for content words versus function words. Single-word reading and writing-to-dictation were complemented by two text-level tasks. For reading, participants read aloud a 100-word passage (5 sentences) adapted from the Scientific Research Associates (SRA) Reading Laboratory story entitled, “Locks and Keys” (Parker & Scannel, 1998). The read-ability level of the passage was second grade according to the Flesch-Kincaid metric (Kincaid, Fishburne, Rogers, & Chissom, 1975). A

writing sample was solicited in response to the picnic scene from the WAB using instructions comparable to those for the spoken picture description task (i.e., “Write a paragraph about what is going on in the picture; try to use complete sentences”).

Pre-treatment profiles

All four participants had left perisylvian damage that resulted in anomic aphasia at the time of this study with relatively preserved nonverbal cognitive skills. Their normal hearing was accompanied by good visual processing abilities to perceive orthographic stimuli and relatively preserved allographic and graphomotor control for handwriting (see composite scores in Table 1). Semantic knowledge was also relatively preserved, although Participant 2JW showed a mild impairment relative to healthy control subjects (Table 1).

As illustrated in Figure 1 (middle), participants demonstrated significant impairment in reading and spelling of nonwords compared to real words as is typical of phonological alexia and phonological agraphia. The lexicality effects (words vs. nonwords) were large, averaging 57.5% for reading and 65% for spelling. Consistent with the predictions of the phonological deficit hypothesis of phonological alexia/agrapia, a significant lexicality effect was not only observed in reading, $t(3) = 6.71, p = .007$, and spelling, $t(3) = 15.56, p = .0006$, but also in single word/nonword oral repetition tasks, $t(3) = 2.61, p = .039$. A central phonological deficit was also suggested by the participants’ poor performance on a range of tasks that required the maintenance and manipulation of phonological information. This included tests of phonological short-term memory (e.g., digit span), phonology-orthography transcoding (for single letters and nonwords), and phonological manipulation (e.g., phoneme deletion, replacement, and blending); see composite scores in Table 1 and individual test scores in Appendix A. It is important to note that some tasks that required accurate perceptual analysis and representation of phonological information were performed well (such as rhyme judgement and minimal pairs). In addition, preserved repetition of real words provided evidence of largely intact speech production abilities. Overall, the main difficulty in our patients seemed to involve the ability to maintain and manipulate sublexical information at the level of individual phonemes.

Difficulty writing at the sentence level was apparent for each participant. Excerpts from their written and spoken descriptions of the WAB picnic scene included in Figure 1 (right column) illustrate that the grammatical accuracy and complexity of their written descriptions was impaired relative to their spoken descriptions of the same picture (see Appendix B for complete transcripts). Because the narratives were self-generated and collected on different days, a direct comparison for each sentence in the spoken and written form is not possible; however, some sentence contrasts between the two modalities were striking. For example, whereas Participant 1HT said, “*Devon is playing in the sand,*” she wrote, “*Devon is make is a sand castle*”. An example from Participant 2JW contrasts his spoken sentence, “*He’s walking a dog, or his dog is walking him, I don’t know,*” with his written description, “*Dog is cuming*”.

With regard to reading at the text level, 4RL was not tested at the outset because he indicated that he had no concerns about his reading. 1HT and 3GG showed mild oral reading impairment, with errors on 4% and 10% of the 100-word passage, respectively (see

Appendix B). The errors consisted entirely of the omission or substitution of closed class words or morphological markers. Participant 2JW made 30 errors (per 100 words), with 70% of those affecting closed class words or morphological markers. In contrast to sentence-level reading, Participants 1–3 read closed class words presented in isolation at an average of 85% accuracy (range: 80–90%). This performance did not greatly differ from oral reading of content words in isolation ($M = 92.7\%$; range 88–95%). Thus, the oral reading profiles for participants 1HT, 2JW, and 3GG were consistent with phonological text alexia, albeit mild in case of 1HT and 3GG. Oral reading rates were significantly slower than healthy controls, ranging from 43 to 70 wpm versus controls at 189 ($SD = 27$) wpm.

In summary, the four individuals with anomic aphasia had relatively preserved single word reading (averaging 96.3% correct), whereas spelling to dictation was impaired in three of the four individuals (averaging 83.8% correct). Nonword reading and spelling were very poor, averaging 38.8% and 18.8%, respectively. Thus, the written language profiles were characteristic of phonological alexia and phonological agraphia. The marked impairment of phonological skills was further elucidated by significant impairment of phonology-orthography transcoding and phonological manipulation skills. Oral reading of text was variably affected in three individuals who had profiles consistent with phonological text alexia. The ability to produce well-formed written sentences was notably impaired for all participants. The treatment plan was to remediate the sublexical skills and to facilitate better use of phonology and residual orthographic information to improve spelling.

Phonological treatment

Each participant received phonological treatment using the methods described in Beeson et al. (2010). The intervention comprised a two-part sequence beginning with treatment to improve phoneme-grapheme correspondences for 20 consonants and 12 vowels. Participants 3GG and 4RL had preserved knowledge of consonants, so they required treatment only for vowels and phonological manipulation. Sound-letter correspondences were trained in sets of five (for consonants) or six (for vowels). Twice-a-week treatment sessions included a cueing hierarchy to retrain sound-letter correspondences with reliance on “key words” as needed to assist in self-cueing of target sounds/letters (see additional treatment details in Beeson et al., 2010). Daily homework was structured using video-recorded clinician guidance on DVD for each set of sound-letter correspondences in training.

To monitor progress and assure pre-treatment stability, single-subject multiple baseline designs were implemented for each participant. At least three probes were collected for each set of consonants and vowels for both sound-letter and letter-sound transcoding tasks. Although there was variability by modality (e.g., 2JW was markedly impaired on letter-sound compared to sound-letter correspondences for consonants), none of the participants demonstrated an upward trend in performance prior to treatment. In other words, pre-treatment performance was relatively stable. For each set of phonemes in training, participants were required to reach 80% accuracy or better on sound-letter and letter-sound correspondences. After mastery of sound-letter correspondences, performance was probed on three occasions on the spelling of 20 nonword stimuli (four sets of five) that were not part of the assessment battery. Impaired and relatively stable baseline performance was

demonstrated by all four participants on this task. Participants were trained to segment, blend, and manipulate phonemes in the context of spelling the nonword stimuli. Treatment continued until participants correctly spelled a standard set of 20 nonwords with 80% accuracy or better over two sessions.

The second phase of treatment focused on a problem-solving approach to spelling remediation that relies on interactive use of lexical and sublexical processes (Beeson et al., 2010; Beeson, Rewega, Vail, & Rapcsak, 2000). During treatment, participants were encouraged to attempt to resolve spelling difficulties by “sounding out” words in order to generate phonologically plausible spellings, and then to evaluate and correct the spellings using residual orthographic knowledge. Participants were also trained to check for spelling errors and make corrections using an electronic spell-checker (The Franklin Speaking Language Master™) that is sensitive to phonologically plausible spelling errors.

During interactive treatment, participants were trained to use the problem-solving approach to spelling in the context of writing regularly and irregularly spelled words to dictation. After they learned to identify and resolve errors at the single word level (using the spell-checker as needed), participants were trained to detect and self-correct spelling errors in self-generated written sentences. Participants were prompted to write a sentence, then read it aloud and determine whether or not there were any spelling errors. If an error was identified, they were asked to sound out the word, re-examine for correctness, and use the spell-checker if necessary. For example, Participant 1HT was asked to spell the word *kangaroo* and use it in a sentence. She generated the sentence, “*Kangapoo have a pouch*”. She said the sentence aloud as, “*Kangaroos have a pouch*,” and was able to correct the spelling error in *kangaroo* by “sounding out” the word, changing the *p* to *r* and identifying the need to add *s* for the final phoneme /z/.

Participants were guided toward self-detection and correction of errors in written sentences. That is, they were instructed to read each sentence aloud and to compare their spoken output to the written. If they identified missing words or grammatical morphemes in their written sentences, they were trained to isolate the sounds that were missing and assign correct graphemes. Another example of this approach comes from a therapy session with Participant 2JW who was instructed to generate a sentence from the target word *surgeon*. His initial attempt was: “*My surgeon approve me for surgery*.” When he read the sentence aloud, he said, “*My surgeon approved me for surgery*.” He identified the spelling error in *surgeon* and corrected it using the electronic spell-checker. He was then directed by the clinician to isolate the final phoneme /d/ in the word “approved”, and to write the corresponding grapheme. The focus was on matching written-to-spoken productions and self-detection and correction of spelling errors, but not on training participants to specifically address the syntax of the sentences. Thus, the treatment was orthographic/phonological in nature, rather than grammatical. This approach continued through the final stage of interactive treatment, when participants were provided with topic prompts for writing short paragraphs. Treatment sessions encouraged editing by self-detecting and correcting errors, using the spell-checker as needed.

Daily homework was assigned during interactive treatment, and homework tasks were similar to those completed in therapy. At the single word spelling stage, participants were provided with audio word stimuli (via a “talking” photo album) and were instructed to spell the words they heard using the problem-solving approach. As treatment progressed, participants were also instructed to use those words in sentences. In the final stages of treatment, participants were given a written prompt for paragraph writing. They were encouraged to indicate any words they had difficulty spelling or that they corrected using the spell-checker by circling them or keeping a list of the words in the margin of their paper.

Treatment was consistent across all four participants with the exception that Participant 3GG received oral reading treatment concurrent with interactive spelling treatment. Reading treatment was prompted by his complaint of slow and effortful reading. A multiple oral rereading treatment was implemented in a manner consistent with Beeson, Magloire, and Robey (2005) and Kim, Rising, Rapcsak, and Beeson (2015). This treatment simply involved repeated oral reading of selected passages with the goal of improving rate and accuracy of oral reading.

Analysis of post-treatment performance

Re-administration of the pre-treatment assessment battery allowed for examination of improvements beyond the direct effects of treatment. Item-by-item analysis of pre-versus post-treatment accuracy on assessment tasks was performed using McNemar tests with significance set at $p < .05$. Written and spoken picture description tasks and oral reading were resampled after treatment. Because marked improvement was noted on the grammatical complexity of written narratives, a detailed analysis of the text-level tasks was prompted. As a means to characterise the proportion of errors in the spoken and written modalities, we generated the most plausible target sentences that comprised each narrative and tallied the number of errors relative to the total number of words in the “target” narratives. For example, the plausible target for *man fly kite* would be *The man is flying a kite*. Narrative analysis procedures were adapted from Quantitative Production Analysis (QPA; Berndt, Wayland, Rochon, Saffran, & Schwartz, 2000; Wilson et al., 2010). Errors were coded as those affecting closed class words (e.g., determiners, prepositions, auxiliary verbs, light verbs), morphological markers (e.g., inflectional or derivational affixes), or errors in the selection of open class words (main verbs, adjectives, or nouns). Modality-specific errors were coded, which included paralexias in oral reading (e.g., phonological or semantic errors, visually similar words), spelling errors in written narratives, and paraphasic errors in the spoken narratives. For the written and spoken picture descriptions, individual sentences were judged as to whether or not they were grammatically well formed and complete, and the overall proportion of grammatically acceptable sentences was calculated. Transcription of spoken narratives, and error coding for oral reading of text and written narratives were performed by three individuals; any discrepancies were resolved by consensus.

Results

Each of the four participants successfully completed phonological and interactive spelling treatment phases. The duration of phonological treatment ranged from 6 to 12 weeks depending on the extent to which consonant sound-letter correspondences needed to be retrained before vowels. Interactive treatment was completed over the course of 6 weeks for all participants.

Treatment outcomes for each participant are shown in Figure 2 and Tables 2–6, and post-treatment scores for individual subtests are included in Appendix A.

Participant 1HT received a total of 14 weeks (28 hours) of treatment: 2 weeks to relearn sound-letter correspondences for consonants; 2 weeks for vowels; 4 weeks for phonological manipulation training; and 6 weeks for interactive treatment. She met the treatment criteria for consonants, vowels, and nonword blending, see Figure 2(a), left, and also showed significant generalisation on the phonological transcoding ($\chi^2 = 10.28$, $p = .0013$), and manipulation tasks ($\chi^2 = 40.09$, $p < .001$); see Figure 2(a) right, dashed lines. On the ABRs, 1HT showed generalised improvement in spelling nonwords and untrained real words (see Table 2). Specifically, real word spelling improved from 68.8% to 81.3% and 1HT used the electronic speller independently to resolve residual errors to achieve 95% correct spellings. Of particular note, 1HT demonstrated marked improvement in her production of well-formed, complete sentences on the written picture description task, so that the grammatical quality of the written narrative was similar to her spoken picture description, see Figure 2(a), right, solid lines. Prior to treatment, Participant HT had no errors in her spoken picture description, but half of the sentences in her written narrative were not grammatically well formed or complete. After treatment, her written narrative was without error. Improvements included an increase in the appropriate use of functors and verb inflections. For example, before treatment, 1HT wrote, “*Heidi and Robert are way a picnic. Max is fling a kite*”; after treatment, she wrote, “*Biff and I were out having a picnic. Max was flying a kite and Lucy was standing near him.*” When analysed word-by-word, 1HT’s written narratives showed a reduction in errors from 20% to 0% (see Table 5). She wrote six sentences about the picture, with only half of them well formed and complete before treatment, and all six sentences well-formed and complete after treatment. Her oral reading remained slow at ~55 wpm, but relatively accurate.

Participant 2JW received a total of 22 weeks (44 hours) of treatment: 5 weeks for consonants; 6 for vowels; 5 for phonological manipulation training; and 6 for interactive treatment. He met criterion on all of the training tasks, but had some difficulty maintaining treatment gains for nonword spelling, see Figure 2(b), left. Oral reading and spelling of untrained nonwords significantly improved, as did spelling of words from the ABRs. As shown in Table 2, real word spelling improved from 77.5% to 83.8%, and 2JW corrected residual errors with the electronic speller to achieve 97.5% correct spellings.

Figure 2(b) right, dashed lines, depicts the significant gains 2JW made on composite scores for transcoding ($\chi^2 = 31.15$, $p < .001$) and phonological manipulation ($\chi^2 = 38.75$, $p < .001$). Figure 2(b), right, solid lines, also illustrates the notable improvements 2JW made in

the grammatical accuracy of his picture description. Prior to treatment, he was unable to write any well-formed, complete sentences, whereas after treatment, 50% of his sentences had acceptable grammatical form. Most notable was the increased inclusion of determiners and morphological endings on verbs. For example, prior to treatment he wrote, “*Lady & guy the to picnic and book and with wine*”, whereas after treatment, he wrote, “*The man a reading a book. The lady is pouring wine or soda.*” Although JW still had errors in written sentences, the proportion reduced from 55.1% to 18.4% (see Table 5). On the oral reading tasks, 2JW showed a reduction in errors from 34 to 17 per 100 words, and maintained a reading rate around 1 word per second (~62 wpm).

Participant 3GG received a total of 12 weeks (24 hours) of treatment: 2 weeks for vowels; 4 for phonological manipulation training; and 6 for interactive treatment concurrent with oral reading treatment. He achieved criterion on the trained tasks, see Figure 2(c), left, and demonstrated significant improvement on sound-letter transcoding ($\chi^2 = 20.57, p < .001$) and phonological manipulation ($\chi^2 = 18.94, p < .001$) tasks, see Figure 2(c), right. 3GG showed dramatic improvement in his reading/spelling of nonwords on the ABRS (40% increase for reading and 70% increase for spelling; see Table 2). His reading/spelling of real words was relatively spared from the outset, with reading improving from 92.5% to 100%, and spelling consistently above 96% correct. 3GG used the electronic speller to correct a few of the words that were in error.

After treatment, the grammatical form and complexity of 3GG’s written narrative improved, so that it was closer to the quality of his spoken narrative, see Figure 2(c), right. Prior to treatment, 3GG said, “... *it looks like he’s flying the kite and his dog is next to him,*” but he wrote, “*He fly a kite. He is a the beach. He is a dog.*” Following treatment, 3GG wrote, “*There is a house by the lake. The is a guy flying a kite with his dog.*” Although there were some errors in his post-treatment written sentences, 3GG’s errors decreased from 13% to 6% after treatment, and the percentage of well-formed sentences increased from 57% to 62.5% (see Table 5). Participant 3GG, who had received concurrent oral reading treatment, increased his reading rate from 51 to 109 wpm on the untrained text Locks and Keys, and his error rate reduced from 10 to 3 per 100 words.

Participant 4RL received a total of 13 weeks (26 hours) of treatment: 3 weeks for vowels; 4 for phonological manipulation training; and 6 for interactive treatment. He met criterion on all of the training tasks, see Figure 2(d), left, and showed significant generalisation to transcoding tasks ($\chi^2 = 12.46, p < .001$) and phonological manipulation ($\chi^2 = 24.64, p < .001$), Figure 2(d), right. Spelling accuracy for real words was relatively intact prior to treatment, but it increased to 100% using the electronic spell-checker. He made improvements in reading and spelling nonwords, but they did not reach statistical significance (Table 2). Like Participants 1–3, Participant 4’s written narrative showed marked improvement in the proportion of well-formed sentences, from 33.3% to 80%, with his post-treatment written performance approximating his pre-treatment spoken narrative, see Figure 2(d), right. 4RL’s word-level errors in his written picture description decreased from 14.4% to 1.5% after treatment (see Table 5). A post-treatment sample of text reading from 4RL confirmed relatively strong reading skills at the text level (105 wpm; 1 error/100 words).

Group results

We aggregated the pre–post-treatment data to test changes of interest in this small case series of individuals with phonological alexia/agraphia. After treatment, the average improvement reading ABRS nonwords was 31.25% ($SD = 14.3$), and for spelling it was 50% ($SD = 22.6$). This improvement reduced the gap between performance on words versus nonwords, as reflected by a decrease in the lexicality effect (from 57.5% to 28.75% for reading; from 65% to 20.62% for spelling; Wilcoxon signed-ranks $W = 36$, $p = .005$ for the modalities combined). A reduced lexicality effect was also evident on the spoken repetition task using single words and nonwords. Prior to treatment, real words were repeated without error (100% correct by all), whereas nonword repetition posed some difficulty ($M = 80\%$ correct, $SD = 13.5\%$). After treatment, nonword repetition improved to 95% for all four individuals, so that it was no longer impaired in relation to control subjects, and the lexicality effect was minimal at 5%. As summarised in Table 3, the mean performance of the four participants showed a marked improvement of phonology-orthography transcoding skills (+20%) and phonological manipulation skills (+33%). Analysis of the pre–post-treatment performance across the four transcoding and four manipulation tasks (as detailed in Appendix A) confirmed a significant improvement in phonological skills for this small group (Wilcoxon signed-ranks test, $W = 36$, $p < .005$). In contrast to these changes, phonological short-term memory, as measured by forward digit span, did not improve (see Appendix A).

A consistent finding across participants was improvement in the accuracy of written narratives after treatment that approximated their spoken narratives prior to treatment (Table 5 and Figure 2, right). As noted, improvements reflected greater inclusion and accuracy of morphological markers and functors, such as articles (e.g., *a*, *an*, *the*), auxiliaries (e.g., *is*, *are*), or prepositions (e.g., *at*, *of*, *from*). The average length of words in error before treatment was 3.94 ($SD = 2.35$) and the average length of words in error after treatment was 4.0 ($SD = 2.27$). Thus, as expected, word length was not a significant factor in either pre- or post-treatment performance. The narratives were self-generated so that a direct comparison of pre–post-treatment performance was not possible using a word-by-word or sentence-by-sentence fashion, so we compared the proportion of sentences that were well-formed and complete. As a group, the proportion of well-formed sentences improved from 35% to 73.1%, $\chi^2 = 29.22$, $p < .0001$.

Discussion

At the outset, the four participants in this study demonstrated disproportionate difficulty reading and spelling nonwords compared to real words, thus meeting the diagnostic criteria for phonological alexia/agraphia. The lexicality effect was greater for spelling than reading, and they all showed a marked inability to rely on the sublexical spelling pathway, including impaired ability to convert individual phonemes to graphemes. Additional testing revealed that the dysfunction of sublexical spelling procedures was attributable to an underlying central phonological deficit: that is, defective performance and increased lexicality effects on non-orthographic tasks that required the maintenance, manipulation, and reproduction of phonological information. All these observations are consistent with other reports in the literature and support the phonological deficit hypothesis of phonological alexia/agraphia

(Crisp & Lambon Ralph, 2006; Rapcsak et al., 2009), as does the perisylvian location of their lesions (Henry et al., 2007; Rapcsak et al., 2009).

The marked impairment in nonword reading/spelling was accompanied by sentence-level errors largely consisting of omissions/substitutions of closed class vocabulary items and morphological markers. Three of the participants exhibited features of phonological text alexia and all four demonstrated phonological text agraphia. We use the latter term as the complement to Friedman's (1996) "phonological text alexia" and to emphasise the common underlying phonological deficit that gives rise to the characteristic clinical profile in single word/nonword reading/spelling tasks, as well as the text-level impairment. Support for a phonological rather than grammatical source of the text-level difficulty was evident in that the accuracy and complexity of spoken utterances produced by our participants were notably better than written sentences on a comparable task. The discrepancy between the quality of spoken and written sentences was blatant in some instances when an individual self-dictated a well-formed sentence aloud while producing a written version with functors and affixes missing or in error. The construction of spoken and written sentences engages the same syntactic mechanisms/representations and both output modalities require phonological encoding and maintenance of phonological traces in memory. For speech, phonological codes need to be maintained for articulatory planning and execution. For writing, phonological codes must be held in order to activate the appropriate orthographic representations, by both lexical-semantic and sublexical procedures, and also while the peripheral components of the writing process are implemented (for review, see Rapcsak & Beeson, 2015). Since writing is much slower than speaking, it places greater demands on phonological short-term memory. Thus it is not surprising that the phonological impairment has a more deleterious effect on writing than speaking. Reading, which requires phonological transcoding from print, is likely to be of intermediate difficulty, as observed in our participants.

The text-level deficit that we are calling *phonological text agraphia* has received little attention in the literature, but it is likely to be relatively common in individuals with left perisylvian damage. Such individuals are susceptible to phonological impairment, which is easily detected in the context of nonword reading/spelling tasks, because nonwords have no lexical-semantic representation and thus are fully dependent upon phonological skills. In the context of writing real words, the processing impairment is seen when the information load associated with a particular task exceeds the capacity of the disrupted phonological network/working memory system. Sentence level processing requires holding multiple phonological traces in memory for a longer period of time than single words, increasing demands on the functional capacity of the damaged phonological system. As was evident in our participants, closed-class vocabulary (free and bound grammatical markers) will suffer the most, because these items receive limited top-down semantic support that is available for open class vocabulary items in proportion to the richness of their semantic representations. Because semantic support is limited for functors and grammatical markers, it is not surprising that writing impairments in phonological text agraphia may be more pronounced at the sentence level. That is, the increased demands on phonological working memory capacity creates disproportionate difficulty in maintaining phonological traces for lexical items that cannot benefit from semantic support. By this account, the nonword reading/spelling impairment,

and the single word and sentence-level impairments all have a common origin, namely, phonological impairment due to left perisylvian damage.

The treatment sequence implemented in this study was designed to strengthen sublexical phonological skills and to promote the use of phonology to support written language production. As anticipated, all four individuals demonstrated significant improvement on treated tasks, including mastery of sound-letter correspondences, and the ability to generate plausible nonword spellings. During treatment, they were also trained to “sound out” difficult words with reliance on sublexical sound-letter transcoding to support spelling. Additional training in problem solving directed participants to detect and self-correct errors that might occur from an over-reliance on phonology, and to promote interactive processing of all available phonological, lexical-semantic, and orthographic information. It is difficult to tease apart the distinct therapeutic contributions of the two treatment components in relation to the marked improvement in sentence-level writing because they were designed to build upon one another. In our cohort, sublexical spelling skills improved dramatically over the course of treatment, so the resources available for problem-solving were enhanced. Positive treatment effects generalised to untrained nonwords and real words for reading and spelling, and evidence of stronger phonological skills was also apparent on other measures of phonological awareness and manipulation. On average, the participants improved performance by 30% on tasks that required phonological segmentation, sound deletion, blending, and replacement. Thus, there was a clear improvement in core phonological skills that were not specific to orthography. It is important to note that the improvement did not reflect a change in phonological short-term memory capacity, which remained impaired in all four individuals. Rather, it is likely that the improvement in phonological transcoding and manipulation skills increased the efficiency of the sublexical pathway, thus decreasing demands on the limited phonological short-term memory. The improved function of the sublexical pathway, which was now able to handle nonwords better, also supported the lexical-semantic pathway for items with reduced semantic weight, even at the sentence level. This resulted in greater inclusion and accuracy of functors and morphological markers in written text after treatment, so that the grammatical accuracy of written narratives more closely approximated that of spoken productions. In sum, the treatment outcomes provide strong support for the phonological deficit hypothesis as the underlying cause of phonological text agraphia.

While much research has been dedicated to describing reading and spelling impairments in individuals with phonological alexia and agraphia at the single word level, and some attention has been directed towards sentence-level reading, there are few studies that provide detailed examination of written narrative production in such individuals. These text-level difficulties capture the essence of the functional impairment associated with phonological alexia and agraphia that patients often complain about. The present study suggests that boosting sublexical knowledge and phonological manipulation skills can improve writing at the text level, but more research is needed in order to generalise this finding and to better understand the best candidates for this treatment, including the determination of the level of phonological skill needed to gain benefit in written language production. We emphasise that the commonality and significance of these four cases emerged primarily in a post hoc manner. In other words, we did not make a priori predictions regarding the expectation that

phonological treatment would improve the grammatical construction of written sentences. In fact, we had anticipated the need to implement sentence-level treatment after phonological and interactive treatment. As a consequence, we did not sample written sentence construction and narratives in a more comprehensive manner. In future work, writing to dictation of sentences would provide a sample with a clear and common target to allow examination of the same words presented individually and in a sentence context. This would allow a comparison of single-word versus sentence-level writing by grammatical class as performed by Friedman (1996) for oral reading. We also would have obtained more written samples from our participants before and after treatment, as well as immediately following phonological treatment, before interactive treatment was initiated. Despite the limitations of the available data, the improvement in written sentence construction was striking and consistent across these four individuals.

Another potential limitation of this study relates to the relatively recent onset of language impairment in two individuals, 2JW and 3GG, who were four months post-stroke at the start of the study. Although all participants showed relatively stable performance over the several weeks of pre-treatment probes, we cannot entirely rule out some contribution of natural recovery. We note, however, that 1HT, who was 10 years post-onset, made particularly dramatic improvement in written sentence construction over the course of treatment, demonstrating that the outcomes were not simply related to a natural recovery process. Certainly additional research with a larger cohort would provide the opportunity to confirm the findings from this study, and also might help identify factors other than phonological impairment that could account for sentence writing deficits.

In summary, the participants in this study provide a clear illustration that central phonological deficits manifest difficulties beyond poor nonword reading/writing, namely a profile that we call phonological text agraphia. Their performances before and after treatment indicate that their underlying phonological impairments were associated with omission or mis-selection of functors and inflectional markings that improved after sublexical phonology skills were strengthened. These positive and significant changes suggest that phonological treatment is beneficial for remediating written narrative abilities for individuals with phonological text agraphia. This is important as it gets at the core of the functional impairment in these individuals. The benefit of the treatment was emphasised by Participant 1HT, who said in a post-treatment interview, “I thought I could never write again ... this is really exciting.”

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Figure 1.

Left: Each participant’s lesion location depicted on standard sagittal template. Middle: single word reading/spelling performance demonstrating phonological alexia/agraphia in each participant. Right: excerpts from spoken and written picture descriptions of the WAB picnic scene before treatment. *indicates significant impairment of nonword reading/spelling compared to real word performance.

Figure 2.

Left: Percent correct responses to letter-sound and sound-letter transcoding for single consonants and vowels, and nonwords (pseudowords) before treatment (blue) and after treatment (red). Horizontal line indicates the criterion level for treatment. Right: Pre- and post-treatment accuracy on phonological tasks (sound-letter transcoding and phonological manipulation) and proportion of well-formed sentences on spoken and written picture

description of the picnic scene from the Western Aphasia Battery. *indicates significant improvement on phonological tasks using McNemar test, $p < .05$.

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Table 1

Participant characteristics and performance before treatment, with control group means (standard deviations) for statistical comparison.

Participant	IHT	2JW	3GG	4RL	Controls (n = 32)
Age	52	52	37	78	63.9 (10.9)
Gender	Female	Male	Male	Male	11M:21 F
Education (years)	18	12	15	20	16.3 (2.6)
Handedness pre/post-stroke	R/L	R/R	R/R	L/L	–
Aetiology	MCA Stroke	MCA Stroke	MCA Stroke	MCA Stroke	–
Time post-onset (yrs)	10.33	0.33	0.33	2.5	–
Lesion volume (cm ³)	158.8	71.3	92.9	39.7	–
<i>Western Aphasia Battery</i>					–
Aphasia type	Anomic	Anomic	Anomic	Anomic	–
Aphasia quotient	93.8	82.2	88.4	93.5	
<i>Boston Naming Test</i> (of 60)	55	50 [*]	51 [*]	40 ^{***}	56.3 (2.6)
<i>Ravens Coloured Progressive Matrices</i> (of 36)	34	32	35	29	31.7 (3.6)
<i>WMS-R Digit Span Forward</i> (raw score)	6 [*]	6 [*]	4 ^{**}	2 ^{***}	9.5 (1.8)
Semantic processing ^a	97.6	97.1 [*]	97.4	98.8	98.9 (0.9)
Phonological processing ^a	65.0 ^{***}	53.2 ^{***}	79.7 ^{***}	77.7 ^{***}	96.6 (3.3)
Visual-orthographic processing ^a	98.6	98.8	99.7	98.5	99.1 (1.5)
Allographic and graphomotor skills ^a	100.0	100.0	100.0	100.0	99.3 (1.0)

^aSee Appendix A for individual subtest scores.

Performance significantly impaired relative to control data,

* $p < .05$;

** $p < .01$;

*** $p < .001$, using Crawford and Howell (1998) t -test.

WMS-R = Wechsler Memory Scale-Revised.

Percent correct before and after treatment on oral reading/writing to dictation of single words (80 items) and nonwords (20 items).

Table 2

	Time of test	1HT	2JW	3GG	4RL	Agraphic Average mean (SD)	Controls (n = 32) mean (SD)
<i>Oral reading</i>	Pre	97.5 *	97.5 *	92.5 ***	97.5 *	96.3 (3.0)	99.6 (1.0)
Single Words	Post	97.5 *	100.0	100.0 [‡]	97.5 *	98.8 (1.3) [‡]	
	Pre	15.0 ***	25.0 ***	55.0 ***	60.0 ***	38.8 (22.1)	98.0 (3.6)
Nonwords	Post	35.0 ***	70.0 *** [‡]	95.0 [‡]	75.0 ***	68.8 (25.0) [‡]	
<i>Writing to dictation</i>							
Single Words	Pre	68.8 ***	77.5 ***	96.3	92.5 *	83.8 (12.8)	98.6 (2.8)
	Post	81.3 ***	83.8 ***	97.5	97.5 [‡]	90.0 (8.5) [‡]	
	Post [§]	95 [‡]	97.5 [‡]	98.8	100.0 [‡]	97.8 (2.1) [‡]	
Nonwords	Pre	0.0 ***	15.0 ***	15.0 ***	45.0 ***	18.8 (18.9)	96.4 (4.8)
	Post	75.0 *** [‡]	45.0 *** [‡]	85.0 ** [‡]	70.0 ***	68.8 (17.0) [‡]	

Pre = before treatment; Post = after treatment; Post[§] = after treatment with electronic speller available.

Performance significantly impaired relative to control data,

* $p < .05$;

** $p < .01$;

*** $p < .001$, using Crawford and Howell (1998) t -test.

[‡]Performance significantly improved relative to pre-treatment using McNemar, $p < .05$.

Percent correct before (Pre) and after (Post) treatment on phonological processing composite scores (100 possible). See Appendix A for individual subtest scores.

Table 3

	Time of test	1HT	2JW	3GG	4RL	Agraphic Average mean (SD)	Controls (n = 32) mean (SD)
Phonological Perception/Production	Pre	95.0	95.0	88.8 ^{***}	96.9	93.9 (3.6)	98.4 (2.6)
	Post	98.8	97.5	95.6	98.1	97.5 (1.4)	
Phonology-Orthography Transcoding	Pre	69.2 ^{***}	52.9 ^{***}	86.3 ^{***}	85.8 ^{***}	73.6 (15.9)	98.3 (2.2)
	Post	86.7 ^{***†}	91.7 ^{***†}	98.8 [†]	97.5 [†]	93.7 [†] (5.6)	
Phonological Manipulation	Pre	30.8 ^{***}	11.7 ^{***}	64.0 ^{***}	50.4 ^{***}	39.2 (22.9)	93.2 (5.2)
	Post	70.8 ^{***†}	53.6 ^{***†}	88.5 [†]	77.5 ^{***†}	72.6 [†] (14.6)	

Performance significantly impaired relative to control data.

* $p < .05$;

** $p < .01$;

$p < .001$, using Crawford and Howell (1998) t -test.

[†] Performance significantly improved relative to pre-treatment using McNemar, $p < .05$.

Table 4

Analysis of spoken description of the Western Aphasia Battery picnic scene before and after treatment.

<i>Spoken Picture Description</i>							Controls (<i>n</i> = 12) mean (<i>SD</i>)	
	Time	IHT	2JW	2GG	4RL	Agraphic Average mean (<i>SD</i>)		
Total words	Pre	43	57	181	178	114.75 (.75)	94.3 (49.3)	
	Post	47	70	203	NT	106.7 (84.2)		
Words in assumed target	Pre	40	57	118	166	95.25 (57.8)	89.8 (40.2)	
	Post	45	56	141	NT	80.7 (52.5)		
Errors/total possible % in error	Pre	0/40	6/57	4/118	10/166		1.1 (2.1)	
		0%	10.5% *	3.4%	6%	5% (4.4%)	1.7% (3.7)	
	Post	1	1	3	NT			
		2.2%	1.8%	2.2%		2.1% (.2)		
Error distribution								
Closed class	Pre	0	5	1	8	3.5 (3.7)	0.9 (1.7)	
	Post	1	0	2	NT	1.0 (1.0)		
Morph markers	Pre	0	0	2	1	0.75 (.96)	0.08 (0.3)	
	Post	0	1	0	NT	0.33 (.58)		
Verbs/adjectives	Pre	0	0	1	1	0.5 (.6)	0.08 (0.3)	
	Post	0	0	1	NT	0.33 (.58)		
Other	Pre	2	1	1	2	1.5 (.58)	0.5 (0.7)	
	Post	0	2	1	0	0.75 (.95)		
Proportion of sentences well formed and complete	Pre	7/7	7/9	18/21	14/20		7.8/8.5 (4.2)	
		100%	77.8%	85.7%	70%	83.4% (12.8)	92.8% (13.9)	
	Post	6/6	8/9	19/22	NT			
		100%	88.9%	86.4%		91.8% (7.23)		

NT = not tested.

Performance significantly impaired relative to control data.

* $p < .05$ using Crawford and Howell (1998) *t*-test.

Table 5

Analysis of written description of the Western Aphasia Battery picnic scene before and after treatment.

Written Picture Description							
	Time	IHT	2JW	2GG	4RL	Agraphic Average mean (SD)	Controls (n = 12) mean (SD)
Total words	Pre	32 *	18	71	114	58.8 (43.1)	70.3 (20.1)
	Post	36	37	67	64	51.0 (16.8)	
Words in assumed target	Pre	35	29	77	118	64.8 (41.4)	69.5 (19.4)
	Post	35	38	67	65	51.3 (17.1)	
Errors/total possible % in error	Pre	7/35	16/29	10/77	17/118		1.1 (1.1)
		20% ***	55.1% ***	13% ***	14.4% ***	25.6% (19.9)	1.8% (2.1)
Error distribution	Post	0/35	7/38	4/67	1/65		
		0%	18.4% ***	6% *	1.5%	6.5% (8.3)	
Closed class	Pre	3	12	12	12	9.8 (4.5)	0.5 (0.7)
	Post	0	3	3	1	1.8 (1.5)	
Morph markers	Pre	1	1	1	3	1.5 (1.0)	0.1 (0.3)
	Post	0	2	0	0		
Verbs/adjectives	Pre	1	2	0	0	0.5 (1.0)	0 (0)
	Post	0	0	0	0	0 (0)	
Spelling	Pre	2	1	1	2	1.5 (6)	0.5 (0.7)
	Post	0	2	1	0	0.8 (1.0)	
Proportion of sentences well formed and complete	Pre	3/6	0/4	8/14	5/15		6.3/7 (1.7)
		50% ***	0% ***	57% **	33% ***	35% (25.4)	90.2% (13)
	Post	6/6	3/6	5/8	4/5		
		100%	50% ***	62.5% **	80%	73.1% (21.7)	

Performance significantly impaired relative to control data.

* $p < .05$;** $p < .01$;

$d < .001$, using Crawford and Howell (1998) t -test.

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Table 6

Analysis of oral reading of 100-word passage before and after treatment.

<i>Oral Reading</i>		Time	1HT	2JW	3GG	4RL	Aggraphic Average mean (SD)	Controls (<i>n</i> = 20) mean (SD)
Total Words	Pre	100	100	100	100	100	100 (0)	100 (0)
	Post	100	100	100	100	100	100 (0)	
Reading rate (wpm)	Pre	43 ***	70 ***	51 ***	NT	NT	61.0 (17.0)	191 (19.6)
	Post	55 ***	62 ***	109 ***	105 ***	105	82.5 (28.2)	
Errors (out of 100)	Pre	4 **	31 ***	10 ***	NT	NT	15.0 (14.1)	0.8 (1.1)
	Post	4 **	20 ***	6 ***	1	1	7.8 (8.4)	
Error Distribution								
Closed Class	Pre	3	17	6	NT	NT	8.7 (7.4)	0.4 (0.6)
	Post	1	14	1	1	1	4.3 (6.5)	
Morph Markers	Pre	1	4	4	NT	NT	3.0 (1.7)	0.3(0.4)
	Post	2	1	4	0	0	1.8 (1.7)	
Paralexia	Pre	0	2	0	NT	NT	0.7 (1.2)	0.0 (0.0)
	Post	0	0	1	0	0	0.3 (.5)	
Other	Pre	0	8	0	NT	NT	2.7 (4.6)	0.2 (0.4)
	Post	1	5	0	0	0	1.5 (2.4)	
Error Free Sentences/Total Sentences	Pre	6/10	2/10	3/10	NT	NT		
	Post	60% ***	20% ***	30% ***	30% ***	30% ***	36.7% (20.8)	93.5% (8.5)
	Pre	8/10	2/10	5/10	9/10	9/10		
	Post	80%	20% ***	50% ***	90%	90%	60.0% (31.6)	

NT = not tested.

Performance significantly impaired relative to control data.

* $p < .05$;** $p < .01$;*** $p < .001$, using Crawford and Howell (1998) t -test.