AJSLP

Supplement

Effects of Intensive Phonomotor Treatment on Reading in Eight Individuals With Aphasia and Phonological Alexia

C. Elizabeth Brookshire,[a] Tim Conway,[b] Rebecca Hunting Pompon,[a] Megan Oelke,[a,c] and Diane L. Kendall[a,c]

Purpose: The aim of this study was to investigate effects of a multimodal treatment of phonology, phonomotor treatment, on the reading abilities of persons with aphasia (PWA) with phonological alexia.
Method: In a retrospective, single-group design, this study presents pre-, post-, and 3-months posttreatment data for 8 PWA with phonological alexia. Participants completed 60 hr of phonomotor treatment over 6 weeks. Wilcoxon signed-ranks tests and group effect sizes comparing pre-, immediately post-, and 3-months posttreatment performance on tests of phonological processing and reading were performed.
Results: Group data showed phonological processing and oral reading of real words and nonwords improved significantly posttreatment; these gains were maintained 3 months later. No group improvement was found for reading comprehension; however, one individual did show improvement immediately post- and 3-months posttreatment.
Conclusions: This study provides support that phonomotor treatment is a viable approach to improve phonological processing and oral reading for PWA with phonological alexia. The lack of improvement with comprehension is inconsistent with prior work using similar treatments (Conway et al., 1998; Kendall et al., 2003). However, this difference can, in part, be accounted for by differences in variables, such as treatment intensity and frequency, outcome measures, and alexia severity.

Key Words: alexia, aphasia, reading, phonology, phonomotor treatment

A stroke in the left cerebral hemisphere can result in impairments in language (aphasia) and reading (alexia; Cherney, 2004; Webb & Love, 1983). Phonological alexia has been documented as a frequent subtype of alexia in a group of 100 persons with aphasia (PWA; Brookshire et al., 2012). Phonological alexia is characterized by impaired reading of nonwords (NWs) and unfamiliar real words (RWs) with relatively preserved reading of familiar words. These reading difficulties are attributed to an underlying impairment in phonology (Beeson, Rising, Kim, & Rapcsak, 2010), which interrupts the ability to sound out words using grapheme-to-phoneme correspondence (GPC) knowledge (i.e., sublexical reading), resulting in increased reliance on orthographic-semantic processes (i.e., lexical reading). These terms, *sublexical* and *lexical reading,* are derived from a dual-route model of reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), which proposes a word can be read via a sublexical route relying on phonology and GPC knowledge or via a lexical route relying on semantics and visual word recognition.

Phonological alexia has been described on a reading severity continuum with deep alexia (Crisp & Ralph, 2006; Friedman, 1996). Deep alexia is considered to be a more severe form of phonological alexia. In addition to impaired sublexical route reading, impaired lexical route reading and semantic errors (e.g., reading "boot" for "shoe") are present in deep alexia. The phonological/deep continuum hypothesis is based on observations documenting the gradual decline of semantic errors with persistent phonological errors throughout the course of recovery. Given this overlap in impaired phonology and impoverished sublexical reading abilities, similar reading rehabilitation approaches have been used for phonological and deep alexia.

Previous treatments presented in the phonological/deep alexia literature have focused on enhancing residual orthographic-semantic knowledge (lexical) or remediating

[a]University of Washington, Seattle
[b]University of Florida, Gainesville
[c]Veterans Affairs Medical Center Puget Sound, Seattle, WA
Correspondence to C. Elizabeth Brookshire: lizbrook@uw.edu

Editor: Swathi Kiran
Associate Editor: Edwin Maas
Received August 3, 2013
Revision received October 21, 2013
Accepted January 13, 2014
DOI: 10.1044/2014_AJSLP-13-0083

__Disclosure:__ The authors have declared that no competing interests existed at the time of publication.

impaired orthographic-phonologic knowledge (sublexical). The lexical treatment approaches have predominantly targeted reading text aloud (Cherney, 2010; Kim & Russo, 2010; Orjada & Beeson, 2005) or paired associated learning (Friedman, Sample, & Lott, 2002; Lott, Sample, Oliver, Lacey, Friedman, 2008). Taken as a whole, lexically focused treatments demonstrate improved reading for trained stimuli with limited generalization to untrained items and contexts.

Sublexical treatment approaches have predominantly trained GPC knowledge or sound blending through bigraph-biphone training. Some GPC treatments have succeeded in teaching individual GPCs and reported generalization to reading of untrained stimuli (Beeson et al., 2010; Kendall, McNeil, & Small, 1998; Kiran, Thompson, & Hasimoto, 2001), whereas other GPC studies have failed to show transfer of GPC knowledge to novel phoneme sequences (Mitchum & Berndt, 1991; Nickels, 1992; Peach, 2002). Two bigraph-biphone training studies (Bowes & Martin, 2007; Friedman & Lott, 2002) succeeded in teaching phoneme and syllable blending; however, they showed limited generalization to words with untrained bigraphs.

An alternative phonological/deep alexia treatment approach is to focus on remediating the underlying impairment of phonology more broadly, beyond orthographic-to-phonologic correspondences. This approach targets phonological processing and awareness. *Phonological processing* refers to using the sound structure of language to perform oral and written language tasks, and *phonological awareness* refers to thinking about and manipulating that sound structure (e.g., parsing and blending sounds in a word). Phonological awareness helps develop connections between spoken and written language (Alexander, Andersen, Heilman, Voeller, & Torgesen, 1991) and is considered essential for reading acquisition in children (Melby-Lervåg, Lyster, & Hulme, 2012). Reading treatments targeting phonological processing and awareness have shown to be effective not only for children with developmental dyslexia (Alexander et al., 1991; Torgesen et al., 1999, 2001) but also for acquired phonological and deep alexia in adults with left hemisphere stroke and aphasia (Kendall, Conway, Rosenbek, & Gonzalez-Rothi, 2003; Yampolsky & Waters, 2002). Specifically, The Auditory Discrimination in Depth Program (Lindamood & Lindamood, 1975), later renamed The Lindamood Phoneme Sequencing Program for Reading, Spelling and Speech (LiPS; Lindamood & Lindamood, 1998), has improved reading in children with dyslexia (Alexander & Slinger-Constant, 2004). Modifications of this program have proved effective with adults with alexia (Conway et al., 1998; Kendall et al., 2003). Phonologically based reading treatments are typically multimodal in nature and aim to develop explicit awareness of sensorimotor and metalinguistic features of phonemes through various association tasks (e.g., auditory, articulatory motor, visual, and oral tactile-kinesthetic) to improve phonological processing abilities, ultimately resulting in improved reading skills.

Multimodal, phonologically based reading treatments can be theoretically supported by Nadeau's (2001) connectionist model of phonological processing (see Kendall et al., 2008, for a review; see also Figure 1). Although this model is computationally untested, it is neurally plausible and based on the Wernicke–Lichtheim (W-L) information-processing model of language (Lichtheim, 1885). However, unlike the modular framework of the W-L model, Nadeau's model supports a parallel distributed processing framework. Nadeau proposed that phonologic representations are stored as distributed patterns of connectivity within and between auditory, articulatory motor, orthographic, and semantic/conceptual domains. Units of knowledge within each of these domains are based on the strength of the connections between the units, both within and across domains. These connections can be strengthened through learning. Therefore, multimodal learning results in strengthened, distributed connections between phonemes and phoneme sequences and their associated orthographic, auditory, and articulatory-motor representations. These distributed phonologic representations are thought to be rapidly and simultaneously engaged via synaptic activity during verbal and written language tasks. Due to this inherent interconnectivity, input into any domain of the phonologic network should lead to engagement of other domains. For example, input into the acoustic domain (e.g., auditory input /b/) should simultaneously engage the orthographic representation (e.g., letter *b*).

For an individual with phonological alexia and weakened phonological networks, this model would support the notion that access to orthographic representations will largely depend on the relative strength or weakness of other phonologic representations (e.g., auditory, motor, etc.). Therefore, multimodal phonologic treatment can lead to improved reading by targeting and strengthening phonologic representations in all domains, which can help improve access to orthographic representations essential for reading.

The purpose of the present study was to examine the effects of a multimodal treatment of phonology, phonomotor treatment, on the reading abilities of eight PWA with phonological alexia. The present study extends previous work by Conway et al. (1998) and Kendall et al. (2003) and is unique in that fewer hours of treatment were used (i.e., 60 hr compared with 101.1 hr in Conway et al. and 162.5 hr in Kendall et al.), and training of RWs was introduced.

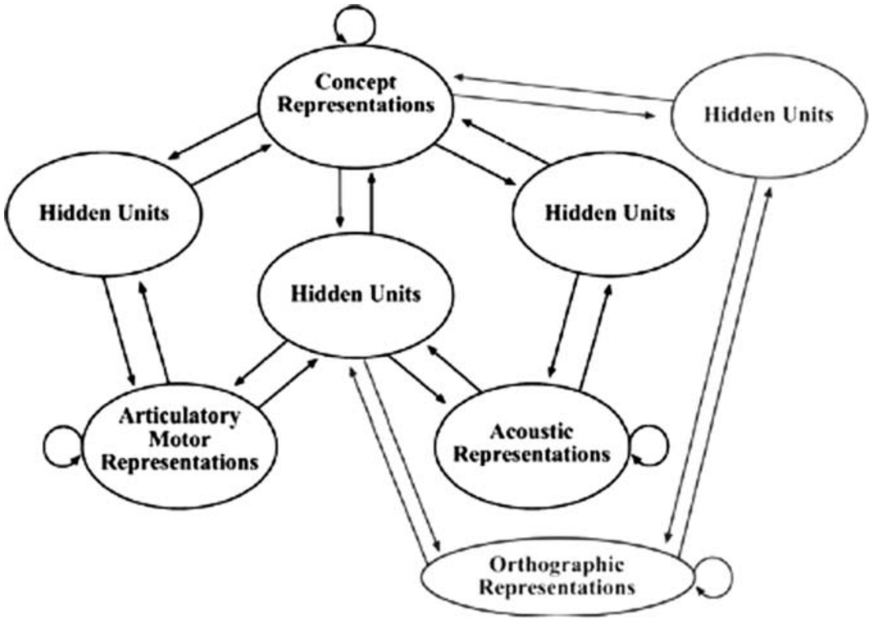
In the context of a retrospective, single-group, pre-/posttreatment design, we asked whether phonomotor treatment improved phonological processing (Research Question [RQ] 1) and whether treatment generalized to the following untrained items: oral reading of nonwords (RQ 2a) and of real words (RQ 2b) and reading comprehension of single words and passages (RQ 2c). In addition, we inquired whether effects of treatment were maintained at 3-months posttreatment (RQ 3).

Method

Participants

Data were analyzed from a group of PWA who participated in a larger phonomotor treatment study aimed to

Figure 1. Schematic of Nadeau's (2001) connectionist model of phonological processing. Reprinted from Kendall et al. (2008), with permission from Elsevier.



improve word retrieval deficits (Kendall, Oelke, Brookshire, & Nadeau, 2013). In the larger study, phonomotor treatment was provided to 26 participants, with confrontation naming being the primary outcome. This study is reporting only on the secondary outcome measures of phonological processing and reading for a subgroup of the participants (described below).

All participants provided informed consent approved by the University of Washington Institutional Review Board (IRB) before entering the larger study. A reading battery was approved by the IRB and added as an outcome measure near the end of the larger study; therefore, only nine of the 26 participants completed reading testing. Eight of these individuals were diagnosed with phonological alexia (described below) and included in this study. The ninth participant was excluded due to lack of disparity between his RW reading range (83.96%–76.42%) and NW reading range (84.44%–66.67%) on the Woodcock Reading Mastery Tests—Revised (WRMT–R; Woodcock, 1987).

The average age of participants was 61.88 years (SD = 15.36) and average education 15.90 years (SD = 2.59). Inclusion criteria included presence of phonological alexia, at least 6-months postonset of left hemisphere stroke (documented by brain magnetic resonance imaging or computed tomography report), right-handedness, and monolingual English. Exclusion criteria included right hemisphere lesion, uncorrected vision or hearing impairment, depression, psychiatric diagnosis, or severe apraxia of speech (AOS). AOS was considered severe if individuals were unable to produce (or repeat) single syllables as a result of speech motor planning/programming (SMPP) difficulties.

Participants' pretreatment nonverbal cognitive, overall language, naming, reading, and phonological processing abilities were measured by performance on the Coloured Progressive Matrices (Raven, 1978), Western Aphasia Battery (Kertesz, 1982), Boston Naming Test (Kaplan, Goodglass, Weintraub, & Segal, 1983), WRMT–R (Woodcock, 1987), and Standardized Assessment of Phonology in Aphasia (SAPA; Kendall et al., 2010), respectively (see Table 1).

The SAPA is a tool to identify phonological deficits and act as an outcome measure for clinical treatment protocols. The SAPA consists of three subtests that use tasks to engage phonological processes. Subtest 1 consists of reading aloud regular, irregular, pseudohomophone, and NWs. Subtest 2 consists of auditory judgment tasks including RW and NW rhyme, minimal pair detection, and lexical decision. Subtest 3 consists of repetition, parsing, and blending of RWs and NWs. Item response theory (IRT) was used in the development of the SAPA. IRT statistics have been preliminarily applied to n = 47 PWA to test psychometric properties of interest, which resulted in acceptable construct validity, sensitivity, and test–retest reliability (Kendall et al., 2010).

The presence of phonological alexia was determined if RW reading abilities surpassed NW reading abilities on the WRMT–R. To determine whether a disparity existed, the standard error of measurement (SEM) was subtracted and added from the RW and NW raw scores for each individual to create an estimated range of reading ability. Due to differences in the number of reading stimuli on the WRMT–R (i.e., 106 RWs, 45 NWs), these values were converted to percentages for comparison. If the RW reading range was greater than the NW range (and there was no overlap between

Table 1. Participant characteristics before treatment.

Participant	Age (years)	Months poststroke	Education	Diagnoses	WAB AQ (out of 100)	BNT (out of 60)	Ravens (out of 36)	SAPA (out of 151)	WRMT–R Reading Cluster (*M* = 100)	Real word (RW) reading range (± 1 *SEM*)	Nonword (NW) reading range (±1 *SEM*)	Difference between RW and NW reading ranges
1	74	8	18	Aphasia, alexia	91.3	51	35	105	98	85.85%–78.30%	55.56%–37.78%	22.74%
2	30	14	14	Aphasia, alexia, AOS	50.8	5	33	50	29	34.91%–27.36%	22.22%–0%	5.14%
3	78	41	13	Aphasia, alexia	90.2	46	29	105	95	84.91%–77.36%	66.67%–48.89%	10.69%
4	61	15	16	Aphasia, alexia, AOS	95	50	33	110	96	90.57%–83.02%	42.22%–24.44%	40.80%
5	67	21	15	Aphasia, alexia	86.6	18	32	124	92	91.50%–83.96%	77.78%–60.00%	6.18%
6	72	144	20	Aphasia, alexia	62.5	14	30	78	49	41.51%–33.96%	24.44%–0%	9.52%
7	61	154	18	Aphasia, alexia, AOS	92	32	34	109	95	99.10%–89.62%	73.33%–55.56%	16.29%
8	52	22	13	Aphasia, alexia, AOS	74.3	41	29	96	53	53.78%–46.23%	33.33%–15.56%	12.90%
M (*SD*)	61.88 (15.36)	52.38 (60.47)	15.88 (2.59)		80.34 (16.19)	32.13 (17.77)	31.88 (2.30)	97.13 (23.12)	75.88 (27.59)			15.53% (11.67%)

Note. WAB AQ = Western Aphasia Battery (Kertesz, 1982) aphasia quotient; BNT = Boston Naming Test (Kaplan et al., 1983); Ravens = Coloured Progressive Matrices (Raven, 1978); SAPA = Standardized Assessment of Phonology in Aphasia (Kendall et al., 2010); WRMT–R = Woodcock Reading Mastery Tests—Revised (Woodcock, 1987).

ranges), then the participant met our phonological alexia criteria. As a group, the participants in this study demonstrated superior RW reading abilities, with a 15.53% (SD = 11.67%) average disparity between the lower limit of their RW reading range and the top limit of their NW reading (see Table 1). It should be noted that each participant made between one and three semantic reading errors during RW or NW reading; however, the majority of reading errors were phonological in nature. Therefore, we deemed the participants' reading to present more similarly to phonological alexia on the phonological/deep continuum.

Review of online transcriptions of participants' oral reading responses did not reveal notations for characteristics of AOS (e.g., sound distortions, distorted substitutions, slowed speech rate characterized by lengthened segment, and intersegment durations and abnormal prosody). Thus, reading errors appeared primarily phonologic, reflecting language impairment. However, because narrow phonetic transcription was not performed, we cannot definitively rule out the possibility that some errors may reflect motor speech impairment. This is important to note because four participants presented with co-occurring mild to moderate AOS (see Table 1), as detected during initial assessment by four experienced speech-language pathologists (SLPs) during conversational speech, picture description, and/or repetition tasks.

Treatment Program

Phonomotor treatment consisted of 60 one-hour treatment sessions, two sessions a day, 5 days a week for 6 weeks. Treatment was delivered by one of two certified SLPs trained via 60 supervised hours with the primary investigator (PI) before administering the treatment independently. Treatment fidelity was evaluated via weekly meetings and periodic cotreatments with the PI.

The treatment program was modified from LiPS (Lindamood & Lindamood, 1998) and has been described in Kendall, Hunting Pompon, Brookshire, Minkina, and Bislick (2013). Therefore, only an overview is provided. Phonomotor treatment is a multimodal, phonologically based program designed to train phonemes and phoneme sequences in spoken language tasks before transitioning to written language tasks. The first stage of treatment (approximately 20 hr) focuses on training English phonemes in isolation. The second stage focuses on training phoneme sequences in one- and two-syllable NWs and then RWs (described below). In Stage 1, each phoneme is trained multimodally by teaching motor descriptions (e.g., top and bottom lip come together for /*p*/), perceptual discrimination (e.g., are /*p*/ and /*b*/ same or different?), production (e.g., repeat /*p*/), and GPCs (e.g., what sound does the letter "P" make?). Phonemes are initially trained via mouth pictures and categorized according to place or manner of articulation (e.g., lip, tongue, nose, or air sounds). As the participant's ability to produce and perceive sounds improves, mouth pictures are faded, and small blocks and/or letter tiles are used to represent phonemes. Once the participant is able to perceive and produce all individual phonemes, Stage 2 begins. This stage builds on Stage 1 and includes training phoneme sequences via phonological awareness tasks (e.g., repetition, minimal pair discrimination, parsing and blending tasks with NWs and RWs), and these tasks are scaffolded into reading and spelling tasks. Training progresses from simple one-syllable phoneme sequences (e.g., "eep") to more complex one- and two-syllable NWs (e.g., "broiz") and finally to RWs (e.g., "plane"). Participants receive feedback via Socratic questioning throughout treatment.

Treatment Stimuli

Trained stimuli were composed of English phonemes in isolation (n = 40) and one- and two-syllable NWs (n = 72) and RWs (n = 42; see the Appendix). RWs were controlled for the following linguistic properties: frequency, imageability, age of acquisition, syllable number and complexity, and semantic category. RWs and NWs consisted of low phonotactic probability (PP) and high neighborhood density (ND) values. PP is determined by positional segment frequency (i.e., how often a phoneme occurs in a word position) and sum biphone frequency (i.e., probability of phoneme segments occurring together in a word). ND can be thought of as the number of words in a dictionary that differ from the target word by a single phoneme addition, deletion, or substitution. A word can consist of both high (or both low) PP and ND values, or a word can be low on one value while being high on the other. For example, the NW *heef* consists of low PP and high ND (Storkel, Armbruster, & Hogan, 2006). The rationale to train words with low PP and high ND is based on work by Storkel et al. Their results suggest that phonological and lexical processing influence different aspects of word learning, with low PP assisting new learning and high ND assisting the integration of new lexical representations with existing representations. Stimuli were calculated via The Irvine Phonotactic Online Dictionary (IPHOD) calculator Version 2.0 (Vaden, Halpin, & Hickok, 2009). NWs were created by changing a single phoneme in one of the RWs, and IPHOD was used to recalculate PP and ND values. These values were classified as high or low on the basis of a median split (Storkel et al., 2006).

Outcome Measures

A certified SLP and/or trained doctoral student administered all outcome measures the week prior to treatment, the week following treatment, and 3 months later. Given the length of time between testing periods, we do not believe practice effects impacted performance. The outcome measures are described below per research question.

RQ 1 asked whether treatment improved phonological processing. To measure this outcome, performance on two tasks, SAPA and NW repetition, was assessed. Following testing procedures, the SAPA was administered via PowerPoint, and participants were seated a comfortable distance from a 20-in. Dell monitor. The computer screen was manually advanced by the administrator after each item, and responses were scored online. The SAPA was scored on the basis of performance on all three subtests; however, performance on individual subtests is provided in Table 2 for the interested reader. For the NW repetition task, participants were seated in front of the same monitor to view video recordings of a male speaker producing one- and two-syllable NWs (described previously). Each NW was a single recording that was advanced manually. A comfortable volume was determined for each participant during practice trials. Participants wore a head-mounted microphone, and responses were recorded with a Marantz professional audio recorder (Model PMD671) for subsequent reliability analysis. Verbal responses were scored online for accuracy. Incorrect responses included phonologic substitutions, additions, deletions, neologisms, and omissions. Distortions were scored as correct.

RQ 2a asked whether treatment generalized to sublexical reading as measured by oral reading performance of NWs from the WRMT–R Word Attack subtest. This subtest consisted of 45 NWs ranging from one to four syllables in length (e.g., "tay").

RQ 2b asked whether treatment generalized to lexical reading abilities. To measure this outcome, oral reading performance of RWs on the WRMT–R Word Identification subtest was assessed. This subtest consisted of 106 RWs composed of 49 regular and 57 irregular spellings ranging from one to four syllables in length. Regularly spelled words consisted of common GPCs (e.g., *sheep*), whereas irregularly spelled words contained at least one uncommon GPC (e.g., *brought*; Rapcsak et al., 2009).

RQ 2c asked whether treatment generalized to reading comprehension at the single-word and passage level as measured by performance on the WRMT–R Word Comprehension and Passage Comprehension subtests. Word comprehension involved initial silent reading of single words followed by a verbal response to complete antonym (e.g., "stop–go"), synonym (e.g., "big–large"), and analogy (e.g., "snow–cold, sun–hot") tasks. Passage comprehension consisted of a cloze procedure task that involved silent sentence reading followed by verbal production of a word to complete the sentence.

RQ 3 asked whether treatment effects were maintained. To measure this outcome, participants returned for 3-month follow-up testing, and performance on NW repetition, SAPA, and WRMT–R subtests was assessed.

Data Analysis

To account for nonparametric data, two-tailed Wilcoxon signed-ranks tests were used to compare pre-/post- and pre-/3-months posttreatment performance on NW repetition, SAPA, and WRMT–R subtests. Given differences in number of stimuli per test, data were analyzed in percent correct to allow for direct comparison across outcome measures.

Group effect sizes (ES) were calculated using change (or gain) scores. Change scores were used to account for variability in performance. ES on change scores for acquisition (immediate posttreatment) and maintenance (3-months posttreatment) for all outcome measures were calculated using the following formula: ES = $\text{Mean}_{\text{change score}}/SD_{\text{change score}}$. This formula is a derivative of Robey's (1994) repeated measures ES calculations (0.63, 1.58, 2.53), which are derivatives of Cohen's (1988) independent samples ES calculations (0.2, 0.5, 0.8). For repeated measures, Robey suggested to base ES cutoffs on the following: d (repeated measures) = d (independent measures)/$\sqrt{1-\rho(pre-post)}$. To account for interpretation of change scores, ES cutoffs in this study are equal to Robey's values divided by $\sqrt{2}$ or Cohen's values divided by $\sqrt{0.2}$ when there is a high pre–post correlation of rho (ρ) = 0.90. Thus, in this study, small, medium, and large ES cutoffs are 0.45, 1.12, and 1.79, respectively (S. Wu, personal communication, May 28, 2013).

Reliability

Point-to-point reliability was performed on 30% of the NW repetition task recordings. Intraclass correlations showing reliability were .95 for intrarater agreement and .90 for interrater agreement.

Table 2. Proportion correct for individual performance on phonological processing tasks (SAPA and repetition of trained nonwords) at pre-, immediate post-, and 3-months posttreatment.

	SAPA total			SAPA Subtest 1 (Reading)			SAPA Subtest 2 (Auditory Phonological Processing)			SAPA Subtest 3 (Repetition, Parsing, Blending)			Nonword repetition task		
Participant	Pre	Post	3 months	Pre	Post	3 months	Pre	Post	3 months	Pre	Post	3 months	Pre	Post	3 months
1	0.70	0.77	0.75	0.75	0.77	0.75	0.77	0.80	0.80	0.47	0.74	0.65	0.85	0.91	0.92
2	0.33	0.62	0.55	0.13	0.56	0.42	0.62	0.75	0.72	0.09	0.47	0.41	0.25	0.57	0.60
3	0.70	0.80	0.80	0.77	0.77	0.79	0.85	0.89	0.92	0.29	0.68	0.59	0.75	0.84	0.86
4	0.73	0.83	0.83	0.79	0.83	0.83	0.82	0.88	0.91	0.47	0.76	0.71	0.75	0.89	0.88
5	0.82	0.81	0.85	0.88	0.88	0.90	0.83	0.77	0.88	0.71	0.76	0.74	0.95	0.97	0.95
6	0.52	0.52	0.52	0.33	0.35	0.31	0.89	0.77	0.82	0.09	0.32	0.26	0.54	0.80	0.64
7	0.72	0.81	0.81	0.65	0.83	0.77	0.88	0.91	0.91	0.53	0.59	0.71	0.68	0.81	0.79
8	0.64	0.75	0.75	0.56	0.67	0.60	0.85	0.88	0.94	0.35	0.62	0.62	0.87	0.89	0.87
M	0.64	0.74	0.73	0.61	0.71	0.67	0.81	0.83	0.86	0.38	0.62	0.58	0.71	0.84	0.81
SD	0.15	0.11	0.13	0.26	0.18	0.21	0.09	0.06	0.07	0.21	0.16	0.16	0.22	0.12	0.13

Results

In this study, we were primarily interested in group performance (see Figure 2); however, individual data are presented in Table 1 and Table 2 to provide the reader with additional information.

RQ 1: Improved Phonological Processing

Pretreatment SAPA performance was 64% accurate (SD = 15%) and immediately posttreatment 74% accurate (SD = 11%), indicating significant improvement (Z = 2.24, p = .025) (ES = 1.06, small). Pretreatment NW repetition performance was 71% accurate (SD = 22%) and immediately posttreatment 84% accurate (SD = 12%), indicating significant improvement (Z = 2.52, p = .012) (ES = 1.19, medium).

RQ 2a: Generalization to NW Reading

Pretreatment NW reading was 40% accurate (SD = 23%) and immediately posttreatment 54% accurate (SD = 19%), indicating significant improvement (Z = 2.52, p = .012) (ES = 1.15, medium).

RQ 2b: Generalization to RW Reading

Pretreatment RW (regular and irregular) reading was 69% accurate (SD = 25%) and immediately posttreatment 75% accurate (SD = 20%), indicating significant improvement (Z = 2.31, p = .021) (ES = 1.02, small). To determine whether improvement was driven by greater improvement in regular or irregular words, performance on these two word types was compared. There was a significant difference (Z = 2.52, p = .012) in accuracy of reading regular (M = 82.57%, SD = 23.78%) and irregular (M = 58.34%, SD = 26.50%) words before treatment. Posttreatment regular word reading improved to 85.71% (SD = 17.66%), though this improvement was not statistically significant (Z = .95, p = .34). Irregular word reading significantly improved to 66.23% accurate (SD = 22.56%) (Z = 2.38, p = .017) (ES = 1.44, medium). The disparity in regular and irregular word reading remained significant immediately posttreatment (Z = 2.52, p = .012), with greater accuracy of regular word reading.

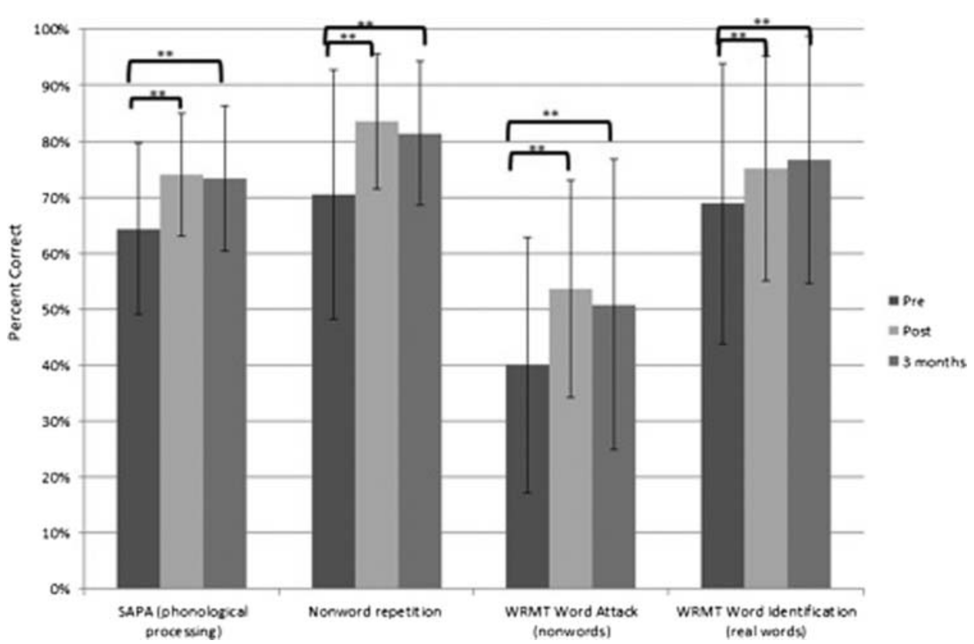
RQ 2c: Generalization to Reading Comprehension

Pretreatment single-word comprehension was 40% accurate (SD = 18%) and immediately posttreatment 43% accurate (SD = 16%). Pretreatment passage comprehension was 52% accurate (SD = 29%) and immediately posttreatment 55% accurate (SD = 24%). Results showed no statistically significant improvement for word or passage comprehension (Z = 1.12, p = .26; Z = 0.84, p = .40, respectively).

RQ 3: Maintenance of Treatment Effects

SAPA accuracy was 73% (SD = 13%) at 3-months posttreatment compared with 64% (SD = 15%) pretreatment, indicating maintained performance (Z = 2.37, p = .018) (ES = 1.37, medium). NW repetition performance was also maintained with 81% accuracy (SD = 0.13) at follow-up compared with 71% (SD = 22%) pretreatment (Z = 2.21, p = .027) (ES = 0.99, small).

Figure 2. Group performance on Standardized Assessment of Phonology in Aphasia (SAPA), nonword (NW) repetition, and oral single-word reading on the Woodcock Reading Mastery Tests—Revised (WRMT–R) at pre-, post-, and 3-months posttreatment. Error bars indicate standard deviation. **p < .025 (after multiple comparison correction).



Oral NW and RW reading remained significant with an accuracy of 51% (*SD* = 26%) ($Z = 2.20$, $p = .028$) (*ES* = 1.03, small) and 77% (*SD* = 22%) ($Z = 2.52$, $p = .012$) (*ES* = 1.49, medium), respectively. Within RW reading, regular word reading improved to 86.99% accuracy (*SD* = 17.59), though this improvement was not statistically significant ($Z = 1.89$, $p = .06$). Irregular word reading significantly improved to 67.76% accuracy (*SD* = 26.04%) ($Z = 2.52$, $p = .012$) (*ES* = 2.15, large). The disparity in regular and irregular word reading remained significant ($Z = 2.52$, $p = .012$), with greater accuracy of regular word reading.

Single-word reading comprehension accuracy was 45% (*SD* = 16%) compared with 40% (*SD* = 18%) pretreatment, and passage comprehension accuracy was 55% (*SD* = 26%) compared with 52% (*SD* = 29%) pretreatment; however, these improvements did not demonstrate statistical significance ($Z = 1.52$, $p = .13$; $Z = 1.81$, $p = .07$, respectively).

Discussion

The purpose of this study was to investigate whether phonomotor treatment improved phonologic and reading abilities in eight PWA with phonological alexia. Overall, results showed improved phonological processing and oral reading skills for RWs and NWs immediately posttreatment, with maintenance of those skills 3 months later; however, no group improvement in reading comprehension was observed.

RQ 1 asked whether treatment improved phonological processing as measured by performance on the SAPA and a NW repetition task. The results provide further evidence that intensively training phonemes and phoneme sequences via multimodal input can result in overall improved phonological processing abilities and are consistent with prior treatments for adults with alexia (Conway et al., 1998; Kendall et al., 2003) and children with dyslexia (Alexander et al., 1991; Torgesen et al., 1999). Improved phonological processing in this context may reflect strengthened phonologic connections between acoustic representations and articulatory motor representations (Nadeau, 2001; see also Figure 1).

RQ 2 asked whether treatment effects generalized to untrained items. Results of RQ 2a showed generalization to sublexical reading abilities (untrained NWs) and are similar to findings from prior phonologic treatment studies in acquired alexia (Conway et al., 1998; Kendall et al., 2003; Yampolsky & Waters, 2002) and developmental dyslexia (Alexander et al., 1991; Torgesen et al., 1999, 2001). This improved sublexical reading can be attributed to improved connections between phonology and orthography necessary for reading. Plaut (1999) reported that orthographic representations must activate the appropriate corresponding phonological sequences for accurate oral reading to occur and that this activation is dependent on learned, cooperative connections among these linguistic units. Results from RQ1 suggest that phonological sequence knowledge (how sound sequences are combined and adhere to the regularities of English) improved, and this improvement likely allowed for relearning and strengthening of disrupted orthographic–phonologic connections.

RQ 2b asked whether treatment generalized to lexical reading abilities (untrained RWs). Coinciding with previous phonological treatments (Alexander et al., 1991; Conway et al., 1998; Kendall et al., 2003; Torgesen et al., 1999, 2001; Yampolsky & Waters, 2002), our results illustrate that phonomotor treatment improved RW reading. Regular word reading was significantly more accurate than irregular word reading at pre-, immediate-, and 3-months posttreatment. Though reading of regularly spelled words improved, it was not to a statistically significant degree. This is likely due to ceiling effects at the individual level: Four of the participants read regular words at or above 95% accuracy at pretreatment and at or near 100% accuracy immediately post- and 3-months posttreatment. The remaining participants, however, demonstrated greater impairment at pretreatment and made expected gains. For example, Participant 2 made a 23% increase and Participant 8 made a 12% increase on regular word reading.

However, reading performance on irregular words significantly improved immediately and 3-months posttreatment at the group level. By strengthening phonologic–orthographic connections, treatment may have provided the participants with increased access to their lexicon of visual word forms via more efficient access to phonology. In particular, irregular word improvement is possible because not all of the graphemes in an irregularly spelled word have an uncommon phoneme correspondence. Irregular word improvement supports a connectionist model of reading that proposes all word types are read via one system (Plaut, Seidenberg, McClelland, & Patterson, 1996; Seidenberg & McClelland, 1989). Therefore, we propose that improved phonological processing and sublexical reading contributed to improved lexical reading. The method used to train stimuli during treatment provides further evidence for the previous statement.

During treatment, RW reading tasks were introduced following NW reading tasks to ensure phoneme–grapheme knowledge was strengthened prior to introducing tasks engaging top-down semantic-orthographic processes (i.e., visual lexicon). Sublexical reading skills were trained via individual phoneme–grapheme training, which we propose generalized to whole-word reading abilities. However, improvement in RW reading may also be due to the automatic spread of activation of semantic knowledge, which likely helped to strengthen distributed and bidirectional connections between the orthographic, phonologic, and semantic domains (Plaut et al., 1996).

RQ 2c asked whether treatment generalized to reading comprehension. The group failed to show improved comprehension at the single-word or passage level. This finding is inconsistent with prior work (Conway et al., 1998; Kendall et al., 2003), which showed improved reading comprehension for individuals with phonological alexia after completing similar treatment programs. This difference in findings may be accounted for by differences in treatment duration, alexia severity, and/or outcome measures. The current treatment is substantially shorter in duration, and the participants as a whole presented with more severe aphasia and alexia. Inconsistency in findings may also reflect differences in the dependent measures of reading comprehension. The prior studies revealed positive results with silent reading measures, whereas the comprehension measure in this study required a self-generated verbal response after a period of silent reading. Therefore, existing word retrieval difficulties (anomia) in this sample of PWA may have masked improvement in reading comprehension.

This task effect notwithstanding, we anticipated improvements in single-word comprehension given the findings in similar treatments by Conway et al. (1998) and Kendall et al. (2003). We expected that combined bottom-up (orthography to phonology to semantics) and top-down (semantics to phonology to orthography) processing might have resulted in automatic and simultaneous activation to semantics necessary for single-word comprehension. We did not anticipate significant improvements in passage comprehension, considering this skill is distant from and more complex than phonological processing and oral single-word reading. Researchers have suggested in the developmental dyslexia literature (Torgesen et al., 1999) that explicit training with semantics and reading comprehension skills, in addition to phonological treatment, is likely necessary to see improved reading comprehension.

Despite the lack of group improvement, Participant 2 (P2) demonstrated improved comprehension of single words and passages immediately post- and 3-months posttreatment (see Table 3). Similar to Subject 1 in the Kendall et al. (2003) study, who also showed comprehension improvements, P2 presented with nonfluent aphasia, severe anomia, and moderate AOS. In addition, P2 was young (30 years) and 14 months poststroke onset, which may have positively impacted her brain's ability to learn and adapt (neuroplasticity; Raymer et al., 2008). That said, it is unclear whether P2's improved reading comprehension stems from greater improved phonology and GPC knowledge or greater improved SMPP given that the comprehension tasks required a verbal response. It is likely that both reading and speech abilities improved due to the multimodal training.

Finally, RQ 3 asked whether treatment effects were maintained. Positive results were seen on measures of phonological processing and oral reading of RWs and NWs. These maintenance effects demonstrate that phonomotor treatment is a viable approach to improve these skills with potentially long-lasting effects. Results suggest that once an adequate repertoire of phonological sequence knowledge is achieved, PWA with phonological alexia can continue to build on existing phonologic–orthographic connections when applying this knowledge to everyday reading experiences.

At follow-up testing, the group was trending toward improvement of single-word and passage reading comprehension (see Table 3). One explanation for this trend is the combined effect of improved sublexical reading with simultaneous benefit from context reading clues and residual lexical route processing during text reading opportunities outside of therapy.

Clinical Implications

Results from this study hold clinical relevance. These findings suggest that reading rehabilitation programs for PWA with phonological alexia may benefit from use of an intensive, multimodal treatment approach targeting phonology. We suggest it may be beneficial to use phonological treatment tasks that do not involve orthography or lexical/semantic knowledge in the early stages of therapy. Instead, initial focus should be on enhancing weakened phonologic representations through phonologic tasks that target sounds presented auditorily, pictorially, and tactile-kinesthetically (first in isolation, then longer sequences) before progressing to tasks that engage orthography and lexical/semantic knowledge. Use of auditory phonological processing tasks and RW/NW reading tasks may be most effective in later stages of therapy, considering this treatment's success is likely due to a complementary effect of targeting phonology, sublexical reading, and lexical reading simultaneously (Conway et al., 1998).

Limitations and Future Directions

Four limiting factors deserve discussion. First, four of the eight participants presented with AOS. Given that

Table 3. Proportion correct for individual performance on WRMT–R reading tasks at pre-, post-, and 3-months posttreatment.

	WRMT–R Word Attack (nonwords)			WRMT–R Word Identification (real words)			WRMT–R Word Comprehension (% correct)			WRMT–R Passage Comprehension (% correct)		
Participant	**Pre**	**Post**	**3 months**	**Pre**	**Post**	**3 months**	**Pre**	**Post**	**3 months**	**Pre**	**Post**	**3 months**
1	0.47	0.58	0.53	0.82	0.85	0.88	0.56	0.63	0.56	0.79	0.79	0.81
2	0.11	0.47	0.33	0.31	0.49	0.44	0.28	0.42	0.49	0.19	0.41	0.38
3	0.58	0.73	0.73	0.81	0.88	0.89	0.47	0.43	0.42	0.60	0.59	0.60
4	0.33	0.60	0.60	0.87	0.86	0.93	0.66	0.64	0.67	0.87	0.87	0.88
5	0.69	0.73	0.78	0.88	0.92	0.90	0.42	0.36	0.41	0.59	0.60	0.63
6	0.13	0.22	0.09	0.38	0.45	0.43	0.08	0.14	0.14	0.10	0.16	0.15
7	0.64	0.67	0.76	0.94	0.95	0.98	0.44	0.50	0.53	0.72	0.63	0.71
8	0.24	0.29	0.24	0.50	0.61	0.68	0.33	0.35	0.35	0.28	0.31	0.28
M	0.40	0.54	0.51	0.69	0.75	0.77	0.40	0.43	0.45	0.52	0.55	0.56
SD	0.23	0.19	0.26	0.25	0.20	0.22	0.18	0.16	0.16	0.29	0.24	0.26

all outcome measures required a verbal response, SMPP difficulties may have interfered with performance. It is possible that results reflect improved motor speech abilities, instead of, or in addition to, improved phonological processing and reading skills for those participants. Evidence of possibly improved SMPP skills can be seen in greater improvement on Subtest 3 (production) compared with Subtest 2 (auditory) on the SAPA (see Table 2).

Second, the complex nature of the phonomotor treatment program should be considered. It is not apparent which element of this multistaged treatment (or perhaps combinations of elements) is responsible for the observed positive treatment effects. In addition, we should consider the effect of treatment intensity and frequency. Treatment success may be attributed to the intense and frequent (2 hr/day, 5 days/week for 6 weeks) delivery of treatment.

In addition, this study's results are restricted by inclusion of limited reading comprehension measures: WRMT–R Word Comprehension and Passage Comprehension. Although these tests have been used in other studies to show treatment gain following variations of phonomotor treatment (Conway, et al., 1998; Kendall, et al., 2003), they did not appear to be an ideal measure for the participants in the present study who presented with more severe word retrieval impairments and/or SMPP impairments. In future studies, a reading comprehension measure that involves only silent reading with multiple-choice responses may be a more valid method to evaluate reading comprehension.

A final limitation involves the retrospective study design. This design prevented controlling for certain threats to internal validity. For example, a control group was not included, and there was potential for tester bias (occasionally, the SLP who provided treatment also administered testing). Given these limitations, results from this study should be seen as suggestive evidence that phonomotor treatment may improve phonology and oral reading, in addition to a possible improvement in SMPP (for those individuals with co-occurring AOS).

Future studies using a multimodal reading treatment approach should consider incorporating additional tasks in an effort to achieve greater overall improvement in written language processing. Adding a spelling component to the phonologic treatment program may improve writing, as well as reading abilities, as demonstrated by Beeson et al. (2010) and Conway et al. (1998). Including treatment tasks that explicitly tap into semantics may further enhance word reading (Kiran & Viswanathan, 2008; Yampolsky & Waters, 2002) and potentially improve reading comprehension (Torgesen et al., 1999). Finally, it is important to consider assessing the functional impact of treatment on time spent and the amount of success achieved with everyday reading (e.g., newspaper, menu, and e-mail).

Acknowledgments

This study was supported by Veterans Administration RR&D Merit Review Grant #C6572R. The authors would like to acknowledge and thank all participants and Sam Wu for their contributions to this project.

References

Alexander, A. W., Andersen, H. G., Heilman, P. C., Voeller, K. K., & Torgesen, J. K. (1991). Phonological awareness training and remediation of analytic decoding deficits in a group of severe dyslexics. *Annals of Dyslexia, 41,* 193–206. Retrieved from http://dx.doi.org/10.1007/BF02648086

Alexander, A. W., & Slinger-Constant, A. M. (2004). Current status of treatments for dyslexia: Critical review. *Journal of Child Neurology, 19,* 744–758.

Beeson, P. M., Rising, K., Kim, E., & Rapcsak, S. Z. (2010). A treatment sequence for phonological alexia/agraphia. *Journal of Speech, Language, and Hearing Research, 53,* 450–468. Retrieved from http://dx.doi.org/10.1044/1092-4388(2009/08-0229)

Bowes, K., & Martin, N. (2007). Longitudinal study of reading and writing rehabilitation using a bigraph-biphone correspondence approach. *Aphasiology, 21,* 687–701. Retrieved from http://dx.doi.org/10.1080/02687030701192117

Brookshire, C. E., Bislick, L., Wilson, J., Nadeau, S., Gonzalez Roth, L., & Kendall, D. (2012, November). *The prevalence, nature, and predictors of alexia in individuals with chronic aphasia*. Poster session presented at the American Speech-Language-Hearing Association Convention, Atlanta, GA.

Cherney, L. (2004). Aphasia, alexia, and oral reading. *Topics in Stroke Rehabilitation, 11,* 22–36. Retrieved from http://dx.doi.org/10.1310/VUPX-WDX7-J1EU-00TB

Cherney, L. (2010). Oral reading for language in aphasia (ORLA): Evaluating the efficacy of computer-delivered therapy in chronic nonfluent aphasia. *Topics in Stroke Rehabilitation, 17,* 423–431. Retrieved from http://dx.doi.org/10.1310/tsr1706-423

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108,* 204–256.

Conway, T. W., Heilman, P., Rothi, L. J., Alexander, A. W., Adair, J., Crosson, B. A., & Heilman, K. M. (1998). Treatment of a case of phonological alexia with agraphia using the Auditory Discrimination in Depth (ADD) program. *Journal of the International Neuropsychological Society, 4,* 608–620. Retrieved from http://dx.doi.org/10.1017/S1355617798466104

Crisp, J., & Ralph, M. (2006). Unlocking the nature of the phonological-deep dyslexia continuum: The keys to reading aloud are in phonology and semantics. *Journal of Cognitive Science, 18,* 348–362. Retrieved from http://dx.doi.org/10.1162/089892906775990543

Friedman, R. (1996). Recovery from deep alexia to phonological alexia: Points on a continuum. *Brain and Language, 52,* 114–128. Retrieved from http://dx.doi.org/10.1006/brln.1996.0006

Friedman, R. B., & Lott, S. N. (2002). Successful blending in a phonological reading treatment for deep alexia. *Aphasiology, 16,* 355–372. Retrieved from http://dx.doi.org/10.1080/02687040143000627

Friedman, R. B., Sample, D. M., & Lott, S. N. (2002). The role of level of representation in the use of paired associate learning for rehabilitation of alexia. *Neuropsychologia, 40,* 223–234. Retrieved from http://dx.doi.org/10.1016/S0028-3932(01)00098-7

Kaplan, E., Goodglass, H., Weintraub, S., & Segal, O. (1983). *The Boston Naming Test*. Philadelphia, PA: Lea & Febiger.

Kendall, D. L., Conway, T. W., Rosenbek, J., & Gonzalez-Rothi, L. (2003). Case study: Phonological rehabilitation of acquired phonologic alexia. *Aphasiology, 17,* 1073–1095. Retrieved from http://dx.doi.org/10.1080/02687030344000355

Kendall, D., del Toro, C., Nadeau, S., Johnson, J., Rosenbek, J., & Velozo, C. (2010, June). *The development of a standardized*

assessment of phonology in aphasia. Paper presented at the Clinical Aphasiology Conference, Isle of Palm, SC.
Kendall, D. L., Hunting Pompon, R., Brookshire, C. E., Minkina, I., & Bislick, L. (2013). An analysis of aphasic naming errors as an indicator of improved linguistic processing following phonomotor treatment. *American Journal of Speech-Lanugage Pathology, 22,* S240–S249.
Kendall, D. L., McNeil, M. R., & Small, S. L. (1998). Rule-based treatment for acquired phonological dyslexia. *Aphasiology, 12,* 587–600. Retrieved from http://dx.doi.org/10.1080/02687039808249560
Kendall, D., Oelke, M., Brookshire, C. E., & Nadeau, S. (2013, May). *Intensive phonomotor treatment for anomia in 26 individuals with aphasia*. Poster presented at the Clinical Aphasiology Conference, Tucson, AZ.
Kendall, D. L., Rosenbek, J. C., Heilman, K. M., Conway, T., Klenberg, K., Gonzalez-Rothi, L. J., & Nadeau, S. E. (2008). Phoneme-based rehabilitation of anomia in aphasia. *Brain and Language, 105,* 1–17. Retrieved from http://dx.doi.org/10.1016/j.bandl.2007.11.007
Kertesz, A. (1982). *The Western Aphasia Battery*. New York, NY: Grune & Stratton.
Kim, M., & Russo, S. (2010). Mulitple oral rereading (MOR) treatment: Who is it for? *Contemporary Issues in Communication Science and Disorders, 37,* 58–68.
Kiran, S., Thompson, C. K., & Hasimoto, N. (2001). Training grapheme to phoneme conversion in patients with oral reading and naming deficits: A model-based approach. *Aphasiology, 15,* 855–876. Retrieved from http://dx.doi.org/10.1080/02687040143000258
Kiran, S., & Viswanathan, M. (2008). Effect of model-based treatment on oral reading abilities in severe alexia: A case study. *Journal of Medical Speech-Language Pathology, 16,* 43–59.
Lichtheim, L. (1885). On aphasia. *Brain, 7,* 433–484. Retrieved from http://dx.doi.org/10.1093/brain/7.4.433
Lindamood, C. H., & Lindamood, P. C. (1975). *Auditory discrimination in depth*. Austin, TX: Pro-Ed.
Lindamood, P. C., & Lindamood, P. D. (1998). *The Lindamood Phoneme Sequencing Program for Reading, Spelling and Speech*. Austin, TX: Pro-Ed.
Lott, S. N., Sample, D. M., Oliver, R. T., Lacey, E. H., & Friedman, R. B. (2008). A patient with phonologic alexia can learn to read "much" from "mud pies." *Neuropsychologia, 46,* 2515–2523. Retrieved from http://dx.doi.org/10.1016/j.neuropsychologia.2008.04.004
Melby-Lervåg, M., Lyster, S-A. H., & Hulme, C. (2012). Phonological skills and their role in learning to read: A meta-analytic review. *Psychological Bulletin, 138,* 322–352. Retrieved from http://dx.doi.org/10.1037/a0026744
Mitchum, C. C., & Berndt, R. S. (1991). Diagnosis and treatment of the non-lexical route in acquired dyslexia: An illustration of the cognitive neuropsychological approach. *Journal of Neurolinguistics, 6,* 103–137. Retrieved from http://dx.doi.org/10.1016/0911-6044(91)90003-2
Nadeau, S. E. (2001). Phonology: A review and proposals from a connectionist perspective. *Brain and Language, 79,* 511–579. Retrieved from http://dx.doi.org/10.1006/brln.2001.2566
Nickels, L. (1992). The autocue? Self-generated phonemic cues in the treatment of a disorder of reading and naming. *Cognitive Neuropsychology, 9,* 155–182. Retrieved from http://dx.doi.org/10.1080/02643299208252057
Orjada, S. A., & Beeson, P. M. (2005). Concurrent treatment for reading and spelling in aphasia. *Aphasiology, 19,* 341–351. Retrieved from http://dx.doi.org/10.1080/02687030444000796
Peach, R. (2002). Treatment for phonological dyslexia targeting regularity effects. *Aphasiology, 16,* 779–789. Retrieved from http://dx.doi.org/10.1080/02687030244000103
Plaut, D. (1999). A connectionist approach to word reading and acquired dyslexia: Extension to sequential processing. *Cognitive Science, 23,* 543–568. Retrieved from http://dx.doi.org/10.1016/S0364-0213(99)00015-4
Plaut, D. C., Seidenberg, M. S., McClelland, J. L., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regualr domains. *Psychological Review, 103,* 56–115. Retrieved from http://dx.doi.org/10.1037/0033-295X.103.1.56
Rapcsak, S. Z., Beeson, P. M., Henry, M. L., Leyden, A., Kim, E., Rising, K., … Cho, H. (2009). Phonological dyslexia and dysgraphia: Cognitive mechanisms and neural substrates. *Cortex, 45,* 575–591.
Raven, J. C. (1978). *Coloured Progressive Matrices, Sets A, A_B, B*. Los Angeles, CA: Western Psychological Services.
Raymer, A. M., Beeson, P., Holland, A., Kendall, D., Maher, L. M., Martin, N., … Gonzalez Rothi, L. (2008). Translation research in aphasia: From neuroscience to neurorehabiliation. *Journal of Speech, Language, and Hearing Research, 51,* S259–S275. Retrieved from http://dx.doi.org/10.1044/1092-4388(2008/020)
Robey, R. R. (1994). The efficacy of treatment for aphasic persons: A meta-analysis. *Brain and Langauge, 47,* 582–608. Retrieved from http://dx.doi.org/10.1006/brln.1994.1060
Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96,* 523–568.
Storkel, H. L., Armbruster, J., & Hogan, T. P. (2006). Differentiating phonotactic probability and neighborhood density in adult word learning. *Journal of Speech, Language, and Hearing Research, 49,* 1175–1192. Retrieved from http://dx.doi.org/10.1044/1092-4388(2006/085)
Torgesen, J. K., Alexander, A. W., Wagner, R. K., Rashotte, C. A., Voeller, K. K., & Conway, T. (2001). Intensive remedial instruction for children with severe reading disabilities: Immediate and long-term outcomes from two instructional approaches. *Journal of Learning Disabilities, 34,* 33–58. Retrieved from http://dx.doi.org/10.1177/002221940103400104
Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Lindamood, P., Rose, E., Conway, T., & Garvan, C. (1999). Preventing reading failure in young children with phonological processing disabilities: Group and individual responses to instruction. *Journal of Educational Psychology, 91,* 579–593. Retrieved from http://dx.doi.org/10.1037//0022-0663.91.4.579
Vaden, K. I., Halpin, H. R., & Hickok, G. S. (2009). *Irvine Phonotactic Online Dictionary, Version 2.0* [Data file]. Retrieved from www.iphod.com
Wagner, R. K., Torgesen, J. K., Rashotte, C. A., Hecht, S. A., Barker, T. A., Burgess, S. R., … Garon, T. (1997). Changing relations between phonological processing abilities and word-level reading as children develop from beginning to skilled readers: A 5-year longitudinal study. *Developmental Psychology, 33,* 468–479. Retrieved from http://dx.doi.org/10.1037//0012-1649.33.3.468
Webb, W., & Love, R. (1983). Reading problems in chronic aphasia. *Journal of Speech and Hearing Disorders, 48,* 154–164.
Woodcock, R. W. (1987). *Woodcock Reading Mastery Tests—Revised*. Circle Pines, MN: AGS.
Yampolsky, S., & Waters, G. (2002). Treatment of single word oral reading in an individual with deep dyslexia. *Aphasiology, 16,* 455–471. Retrieved from http://dx.doi.org/10.1080/02687030244000068

Appendix

Phonomotor Treatment Stimuli.

Trained sounds in isolation		Trained Nonwords		Trained Real Words	
IPA symbol	Trained graphemic representation(s)	1 syllable	2 syllable	1 syllabe	2 syllable
p	p	doi (dɔɪ)	chootee (tʃuti)	ape	feeder
b	b	af (æf)	zhuree (ʒɝi)	ache	jockey
f	f	toos (tus)	foekoe (foʊkoʊ)	itch	ivy
v	v	sheev (ʃiv)	leber (lɛbɚ)	edge	gravy
t	t	ek (ɛk)	doem (doʊʌm)	bow	lasso
d	d	dach (dætʃ)	mefoe (mɛfoʊ)	day	tower
k	k	peenz (pinz)	shever (ʃɛvɚ)	hay	shadow
g	g	poa (poʊə)	feether (fiðɚ)	thigh	shoulder
θ	th	meeth (miθ)	toiler (tɔɪlɚ)	cave	treasure
ð	th	ri (rɪ)	izel (ɑɪzl)	maze	ladder
s	s	ish (iʃ)	shaybee (ʃeibi)	boot	teacher
z	z	whup (wʌp)	veeder (vidɚ)	fig	jail
ʃ	sh	breek (brik)	zower (zaʊɚ)	bird	jury
ʒ	zh	voo (vu)	tawthee (tɑθi)	mop	ranger
ʧ	ch	eep (ip)	jiver (dʒɪvɚ)	half	leather
dʒ	j	reesh (riʃ)	wooter (wutɚ)	song	diver
l	l	nie (nɑɪ)	dungee (dʌŋi)	knob	lawyer
r	r	iej (aɪdʒ)	turmee (tɝmi)	gray	level
h	h	zine (zɑɪn)	lekzher (lɛkʒɚ)	plane	owl
w	w	broiz (brɔɪz)	lekee (lɛki)		father
wh	wh	thag (θæg)	juroe (dʒɝo)		heater
m	m	oit (ɔɪt)	shashoe (ʃæsoʊ)		polo
n	n	kur (kɝ)	hoyter (hoɪtɚ)		movie
ŋ	ng	froos (frus)	neenee (nini)		
i	ee	grake (greɪk)	rayzel (reɪzl)		
ɪ	i	choy (tʃɔɪ)	highger (hɑɪgɚ)		
ɛ	e	oos (us)	woewuh (woʊwə)		
eɪ	ae	wap (wæp)	unger (ʌngɚ)		
æ	a	faps (fæps)	miver (mɑɪvɚ)		
ʌ, ə	u	woy (wɔɪ)	jawvee (dʒɑvi)		
ɑ, ɔ	o, aw	awch (ɑtʃ)	prezhur (prɛʒɚ)		
o, oʊ	oe	plown (plaʊn)	foover (fuvɚ)		
ʊ	oo	zae (zeɪ)	pire (pɑɪɚ)		
u	oo	hob (hɑb)	dryper (drɑɪpɚ)		
ɑɪ	ie	veed (vid)	gower (gaʊɚ)		
ju	ue		teever (tivɚ)		
ɔɪ	oi, oy		ibee (ɑibi)		
aʊ	ow, ou				
ɝ, ɚ	er, ir, ur				
ɔr	or				
ɑr	ar				