Cross-modal generalization of anomia treatment to reading in aphasia

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Abstract

Background: Generalization of treatment effects is the ultimate goal of therapy. However, treatment generalization across language modalities is not well understood in the aphasia literature and requires further investigation. This work examined the generalization effects of two word retrieval therapies, Phonomotor Treatment (PMT) and Semantic Feature Analysis (SFA), to reading performance in individuals with aphasia.

Aims: This cross-modal generalization investigation was motivated by the Primary Systems Hypothesis, which proposes reading ability is related to and dependent upon underlying phonological and semantic abilities. Therefore, this study sought to determine if enhanced phonological or semantic knowledge following anomia treatment could influence reading ability.

Methods & Procedures: Reading data collected in a randomized control trial for anomia treatment (Kendall et al., 2019) were retrospectively analyzed. Fifty-eight participants with chronic aphasia were randomly assigned to receive intensive PMT (n = 28) or SFA (n = 30) treatment for 56-60 hours over 6-7 weeks. Reading measures were administered pre-, post- and 3-months after treatment. To identify and compare the extent of treatment generalization to reading, within-group and between-group analyses of variance were performed.

Outcomes & Results: On average, participants in both groups showed positive changes in reading. The PMT group demonstrated significantly improved reading of regularly and irregularly spelled words. The SFA group showed significant gains in reading of regularly spelled words and sentence-level reading comprehension. No statistically significant differences in oral reading or reading comprehension were found between the groups before or after therapy.

Conclusions: These preliminary findings support the Primary Systems Hypothesis and suggest a link between reading ability and phonological and semantic abilities. Results show that one anomia treatment was not superior to the other and the positive influence of both PMT and SFA suggests that reading might be enhanced via intensively delivered treatments that focus on the underlying phonological or semantic impairment. Further investigations of cross-modal treatment generalization are needed to help better understand this relationship between word retrieval and reading and its implication for aphasia treatment.

Keywords: aphasia, anomia, reading, generalization, treatment, primary systems hypothesis

Introduction

The ultimate goal of aphasia treatment is generalization, or carry over, of the treatment effect to an untrained language skill, preferably one that is functional for everyday communication and valued by the individual with aphasia (Coppens & Patterson, 2018; Webster, Whitworth, & Morris, 2015). It is well known, however, that the majority of aphasia treatments result in consistent acquisition of trained stimuli with limited and variable generalization to untrained stimuli or conditions (Best, Greenwood, Grassly, Herbert, Hickin, & Howard, 2013). Therefore, more research investigating treatment generalization is critical to better understand the mechanisms of generalization and to realize the comprehensive impact of aphasia treatment (Webster et al., 2015).

Examination of treatment generalization in aphasia research is usually limited to measuring performance on untrained items within the trained language modality. For example, if treatment targeted spoken language production (e.g., word retrieval) then generalization within spoken language production (e.g., generalization to naming of untrained words) is typically measured. Generalization from one language modality to another (e.g., cross-modal), however, is not as commonly reported (Webster et al., 2015). Given that individuals with aphasia experience impairments across spoken (i.e., talking and understanding) and written (i.e., reading and spelling) language modalities, cross-modal generalization research can help reveal how these four language domains interact and how treatment of one language domain may or may not influence another aspect of language processing. For example, cross-modal aphasia research efforts could focus on investigating the effects of spoken language treatment on written language abilities, which is currently not well understood.

This gap in the literature might reflect a traditionally held belief that spoken and written language impairments seen in individuals with aphasia are common co-occurrences, yet are separate impairments with unique underlying damage (Lambon Ralph & Patterson, 2007). More recently, however, cross-modality aphasia research has shown that spoken language abilities predict written language abilities (e.g., reading and spelling) (Crisp & Lambon Ralph, 2006; Henry, Beeson, Alexander, & Rapcsak, 2012; Madden, Conway, Henry, Spencer, Yorkston, & Kendall, 2018; Rapcsak et al., 2009), suggesting that spoken and written language abilities are highly inter-connected and not distinct entities. These empirical findings are supported by the Primary Systems Hypothesis (Crisp & Lambon Ralph, 2006; Patterson & Lambon Ralph, 1999; Woollams, 2014), which postulates that acquired alexia and agraphia are not independent reading and spelling disorders, but instead reflect the intactness and relatedness of three underlying, primary neural systems (phonological, semantic, visual/orthographic). In other words, a person's phonological and semantic abilities interact with and underpin his or her orthographic abilities.

The primary systems hypothesis developed from the parallel-distributed processing (PDP) connectionist model of single-word processing (Plaut, 1996; Plaut, McClelland, Seidenberg, & Patterson, 1996), which promotes the view that spoken and written word processing involves synchronized activation of semantic, phonologic, and orthographic units, with word knowledge existing as a learned pattern of neural activity that resides in the connections between these distributed language representations. Since word processing results from semantic, phonologic, and orthographic information simultaneously interacting to establish a learned pattern of activation, there are no proposed lexicons or grapheme-phoneme rule systems, as is commonly assumed in classic views of language processing. This model is often referred to as the "triangle model" and comprises three bi-directional pathways: semantics-phonology, phonology-orthography, and orthography-semantics that contribute to language processing, with a division of labor developing as the language system becomes more efficient. As the language system develops, particular language units have more involvement in the final activation pattern, depending on the specific language task or stimulus. For example, when reading irregularly spelled words (e.g., chef), more semantic contribution is expected, whereas when reading unfamiliar or nonwords (e.g., splooch), greater phonological input is critical. However, the final activation pattern consists of some degree of input from all three underlying systems (semantics, phonology, and orthography) given the connected nature of the underlying language network.

In accordance with the Primary Systems Hypothesis, Crisp and Lambon Ralph (2006) proposed that a person's reading profile/alexia type (i.e., within normal limits, surface alexia, phonological-deep alexia, or global alexia) could be predicted by his or her non-orthographic semantic and phonological abilities. Specifically, they proposed that individuals displaying strong abilities in both phonology and semantics would read within normal limits, individuals scoring high on semantics and low on phonology fitting a phonological-deep alexia profile, those with the inverse abilities (low semantics and high phonology) showing characteristics of surface alexia, and individuals performing low on both semantic and phonologic abilities fitting a global alexia profile. These predictions were supported by recent findings from Madden and colleagues

(2018) who showed non-orthographic language abilities predicted reading performance, and furthermore, that severity of alexia reflected severity of semantic and phonologic impairment in a sample of 43 individuals with chronic, stroke-induced aphasia.

The PDP/Primary Systems view and the research cited above support a strong relationship between spoken and written language impairment in aphasia and provide theoretical and empirical motivation for the examination of cross-modal treatment generalization. The current work aimed to investigate cross-modal generalization and test assumptions of the Primary Systems Hypothesis via retrospective examination of reading data from Kendall and colleagues' (2019) randomized control trial (RCT) of anomia treatment. In the larger study, Kendall et al. (2019) compared word retrieval abilities of persons with aphasia after receiving one of two contrasting anomia treatments: Semantic Feature Analysis (SFA; Boyle, 2004; Boyle & Coelho, 1995), a lexical-semantic based treatment that involves participant-generated semantic descriptions of target items; or Phonomotor Treatment (PMT; Kendall et al., 2008; Kendall et al., 2015), a phonology-based treatment that involves multi-modal phonological awareness training of individual phonemes and phoneme sequences. Their results showed that both treatment groups significantly improved naming of trained words and generalization to naming of untrained words that were semantically related (for SFA group) or phonologically related (PMT group) to the trained stimuli. The current study is concerned with a secondary outcome of interest, cross-modal generalization of SFA and PMT to reading.

Reported generalization effects of SFA are currently limited to spoken language outcomes and the effect of SFA on reading is not yet known. SFA has been shown to generalize to untrained spoken language tasks, including naming of untrained nouns (Boyle & Coelho, 1995; Boyle, 2004) and untrained verbs (Lai, Silkes, Minkina, Kendall, 2019). SFA has also shown carry over to spoken discourse (DeLong, Nessler, Wright, & Wambaugh, 2015; Falconer & Antonucci, 2012; Peach & Reuter, 2010; Wambaugh & Ferguson, 2007). It is important to note that several SFA studies have not shown positive generalization effects (Efstratiadou, Papathanasiou, Holland, Archonti, & Hilari, 2018) and the studies demonstrating treatment carry over often report small generalization effects.

Generalization in SFA is thought to be the result of a strengthened underlying semantic network and/or application of SFA procedures as an explicit self-cueing strategy by the individual with aphasia (Efstratiadou et al., 2018; Gravier et al., 2018). The great variability observed in generalization of SFA likely reflects the numerous methods used to implement SFA, which include variations in dosage/frequency, stimuli, number and type of semantic features targeted, clinician versus participant feature generation, and primary outcome measures (Boyle, 2010). Efstratiadou and colleagues (2018) conducted a recent systematic review of SFA and concluded that continued exploration of SFA generalization outcomes, especially at longer maintenance testing and with larger sample sizes, is necessary to better understand the mechanisms behind and clinical effectiveness of this aphasia treatment.

Similar to SFA, the other anomia treatment of interest in this study, PMT, has also been shown to generalize to untrained items. PMT has resulted in improvement across a range of spoken production tasks, including naming of untrained nouns (Kendall et al., 2008; Kendall et al., 2015) and untrained verbs (Kendall et al., 2019), as well as word repetition (Bislick, Oelke, Kendall, 2014; Kendall et al., 2015) and spoken discourse (Silkes, Fergadiotis, Hunting Pompon, Torrence, & Kendall, 2019). Unlike SFA, the cross-modal effect of PMT on reading has been previously measured in three studies. In a case study with an individual with mild aphasia and alexia, Conway et al. (1998) found improved reading comprehension and oral reading and spelling of real words and nonwords on the Woodcock Reading Mastery Test (WRMT-R; Woodcock, 1987) and Battery of Adult Reading Function (Gonzalez-Rothi, Coslett, & Heilman, 1984) immediately post and 2 months following treatment. In 2003, Kendall, Conway, Rosenbek and Gonzalez-Rothi reported improved oral reading of simple consonant-vowel real words and improved reading comprehension performance on the Reading Comprehension Battery for Aphasia (RCBA; LaPointe & Horner, 1998) for two individuals with moderate aphasia and alexia immediately post and 2 weeks post-treatment. It should be noted that these two studies did not implement the current version of PMT. A developmental dyslexia program, The Auditory Discrimination in Depth Program (ADD; Lindamood & Lindamood, 1975), later renamed, The Lindamood Phoneme Sequencing Program for Reading, Spelling and Speech (LiPS©; Lindamood & Lindamood, 1998), was trialed with adults with aphasia in the Conway et al. (1998) and Kendall et al. (2003) studies. Over the years that program evolved into the current day PMT protocol (see Kendall and Nadeau (2006) for a review of the evolution and development of PMT). In a single group pre-post treatment design with eight participants with aphasia and phonological alexia, Brookshire and colleagues (2014) examined reading effects of the current day PMT, which consists of reduced hours (from 100 hours to 60 hours) and inclusion of trained real word stimuli, in addition to the nonword stimuli typically trained. At immediately post and 3 months post-treatment, results showed significantly improved oral reading of untrained real words (regular and irregular) and nonwords with no group –level improvement of reading comprehension on the WRMT-R (Woodcock, 1987); however, one participant did demonstrate significant improvement with her reading comprehension. Together these three PMT studies provide preliminary evidence that this phonologically-based treatment positively influences reading ability for some individuals with aphasia and suggest additional related work with a larger number of individuals with aphasia is warranted.

Regardless of outcome measure (e.g., picture naming or oral reading), generalization of PMT is thought to be the result of an enhanced central phonological system that contributes to both spoken and written language. PMT aims to strengthen phonological sequence knowledge by first targeting individual phonemes, which are the building blocks of language (Madden, Robinson, Kendall, 2017). During language acquisition, and presumably language reacquisition after brain injury, phonemes must be mapped onto semantic representations for spoken language comprehension and production as well as mapped onto orthographic representations for written language comprehension and production. Therefore, PMT is proposed to generalize across language tasks because the building blocks (i.e., phonemes) of English (as opposed to a finite set of words) are trained in an intense and multi-modal manner, and this training is able to continue after therapy when the individual with aphasia resumes participation in daily communication (Kendall & Nadeau, 2016). This maintenance of generalization of phonological processing ability has been demonstrated in PMT studies that showed improved noun retrieval (Kendall et al., 2019), verb retrieval (Lai et al., 2019), discourse production (Silkes et al., 2018, and single word oral reading (Brookshire et al., 2014) on untrained stimuli immediately post-treatment with treatment gains maintained at 3 month follow-up testing.

The current work is motivated by the Primary Systems Hypothesis and broadly aims to contribute to the understanding of aphasia treatment generalization and the relationship between acquired spoken and written language impairments. Specifically, this work aims to examine the effects of a semantically- based (SFA) and phonologically-based (PMT) anomia treatment on reading performance in individuals with aphasia, and additionally to compare the impact on reading between these two treatments. To address these aims, the following research questions are posed:

1. Within the PMT and SFA groups, what are the treatment generalization effects on oral reading (i.e., regular, irregular, and nonwords) and reading comprehension (i.e., word and sentence-level) immediately post-treatment and three months post-treatment?

2. Are there differences in reading generalization effects between the PMT and SFA groups immediately post-treatment and three months post-treatment?

In accordance with the Primary Systems view of language, it is hypothesized that both treatments will generalize to reading, however to different degrees and for different reasons. Based on previous PMT findings previously described and the fact that PMT targets underlying phonological processing, the PMT participants are expected to show improvement on reading tasks that rely more heavily on phonological-orthographic connections, such as reading aloud of nonwords (e.g., flig) and regularly spelled words (e.g., sheep) and even irregular words which benefit from letter-sound knowledge to some degree, with less improvement anticipated for reading comprehension at immediate post and 3 month follow-up testing. SFA enhances semantic processing, and therefore SFA participants are expected to improve on reading tasks that rely more on semantic-orthographic connections, such as irregular word reading (e.g., laugh) and reading comprehension tasks, especially reading comprehension tasks that involve picture stimuli, which automatically engage conceptual-semantic knowledge. This improvement is not expected to be maintained at 3 month testing given the SFA participants in the larger study (Kendall et al., 2019) did not maintain word retrieval abilities at the 3 month follow-up testing and the larger SFA literature reports small generalization effects. Nonword reading performance is not expected to change for the SFA participants. With regard to between-group differences, the

PMT group is hypothesized to show superior reading gains, particularly for oral reading, compared to the SFA group immediately post and 3 months following treatment given the greater emphasis placed on orthography and articulatory-kinematic training during the PMT procedures (see Treatment Procedures below).

Methods

Study Design

This study is a retrospective analysis of reading data that were collected in a between-group RCT for anomia treatment (Kendall et al., 2019). Participants were randomized to receive PMT or SFA, and all participants completed standardized reading assessments (see Reading Outcome Measures below) one week prior to treatment, one week immediately following treatment, and again three months after treatment. Several other outcomes (e.g., picture naming, repetition, discourse) were measured in the larger study; however, these assessments are not discussed in the current study.

Participants

Participants were recruited through the Veterans Affairs Puget Sound Healthcare System and the University of Washington/Portland State University Northwest Aphasia Registry and Repository, as well as local speech-language pathology clinics. Sixty participants were enrolled in the study with 30 individuals completing the SFA protocol and 28 individuals completing the PMT protocol. Two participants were withdrawn (one due to personal emergency and the other due to late discovery of history of head trauma). All participants exhibited chronic aphasia (at least 6 months post onset) due predominantly to left-hemisphere stroke. Two individuals, however, demonstrated right hemisphere lesions; one individual presented with crossed aphasia and another individual had a prior small right calcarine cortex infarct, in addition to a more recent left hemisphere infarct. Per randomization procedures (described below), each treatment group consisted of one participant with history of right hemisphere lesion. It should be noted that a neurologist reviewed neuroimaging results for each participant to help determine eligibility. Both of the individuals with history of right hemisphere lesion demonstrated classical aphasia characteristics and did not present with typical right hemisphere disorder symptoms.

Study inclusion was heterogeneous by design and therefore defined cut-off scores on standardized language measures were not used. Participants needed to demonstrate anomia determined by performance on the Comprehensive Aphasia Test (CAT; Swinburn, Porter & Howard, 2004), and sufficient auditory comprehension to follow basic directions required for completion of testing and treatment. Inclusion also required the presence of phonological impairment, as defined by the Standardized Assessment of Phonology in Aphasia (SAPA; Kendall, del Toro, Nadeau, Johnson, Rosenbek, & Velozo, 2010). Participants with mild to moderate apraxia of speech were included. Apraxia severity was determined by consensus agreement between two certified speech-language pathologists (SLPs) after reviewing video recordings of various speech production tasks. Per self-report, individuals were excluded from study participation if they exhibited untreated depression, degenerative neurological disease, chronic medical illness, and/or severe, uncorrected impairment of vision or hearing. Hearing was also screened with pure tone audiometry and age-associated high-frequency (4,000 Hz) hearing difficulty was allowed given the age of the participants. Table 1 and Table 2 report participants' characteristics and illustrate that both treatment groups were similar in regard to average age (PMT = 63.3 years old; SFA = 63.4 years old), education (PMT = 14.3 years; SFA = 15.2 years), sex (PMT = 13 females, 15 males; SFA = 12 females, 18 males), years post-stroke (PMT = 4.3 years; SFA = 4.1 years), language production per Boston Naming Test (PMT = 21.6/60; SFA =

PMT Participant	Age (years)	Sex	Education level (years)	Duration post onset (years)	Handedness	*Lexical Retrieval* BNT (out of 60)	*Comprehension of Spoken Language* CAT t-score	*Semantic Processing* CAT Memory t-score	*Phonologic Processing* SAPA (out of 144)
1	71	F	15	1.42	R	49	59	62	116
2	46	F	16	1.25	R	23	58	54	79
3	59	F	16	5.25	R	42	50	62	110
4	67	M	12	2.75	R	46	60	62	94
5	70	F	12	6.75	R	6	39	38	61
6	40	F	16	1.83	R	5	51	62	73
7	59	M	18	2.25	R	6	54	54	58
8	71	F	14	0.83	R	36	58	62	111
9	65	M	16	8.42	R	4	44	62	62
10	73	M	16	2.33	R	6	49	54	49
11	73	F	13	2.5	R	12	50	50	100
12	67	M	16	4.17	R	20	53	54	84
13	46	M	13	7.08	L	14	45	50	48
14	59	F	12	3.67	R	0	35	16	30
15	71	F	16	3.67	R	41	52	54	109
16	90	F	12	6.42	L	26	58	54	79
17	63	M	13	4	R	32	45	62	77
18	60	M	14	2.75	L	2	46	62	50
19	46	M	11	24.83	R	3	41	62	41
20	74	F	14	0.92	R	3	44	62	53
21	63	M	16	2	L	2	50	62	35
22	62	M	16	0.83	R	46	58	54	105
23	50	M	12	2.08	R	1	52	62	79
24	67	F	16	1.67	R	39	45	62	93
25	70	M	12	4.42	R	32	56	54	55
26	66	F	12	9.42	R	40	58	62	94
27	65	M	14	1.42	L	52	55	62	88
28	59	M	18	4.17	L/R	16	47	50	60
AVE	**63.3**		**14.3**	**4.3**		**21.6**	**50.4**	**55.9**	**74.8**
SD	**10.6**		**2.0**	**4.7**		**17.8**	**6.6**	**9.8**	**24.9**

Note: AVE = average; SD = standard deviation; M = male; F = female; BNT = Boston Naming Test; CAT Memory = Comprehensive Aphasia Test Memory Composite Score (Semantic Memory + Recognition Memory); SAPA = Standardized Assessment of Phonology in Aphasia

SFA Participant Number	Age (years)	Sex	Education level (years)	Duration post onset (years)	Handedness	*Lexical Retrieval* BNT (out of 60)	*Comprehension of Spoken Language* CAT t-score	*Semantic Processing* CAT Memory t-score	*Phonologic Processing* SAPA (out of 144)
29	72	M	20	2	R	11	45	62	59
30	69	M	19	8.5	L	28	50	62	61
31	38	F	12	3.42	R	38	48	62	100
32	72	F	16	2.25	R	46	56	54	106
33	57	M	10	0.92	R	4	47	54	49
34	44	F	16	0.75	R	50	57	62	112
35	45	M	14	1	R	7	52	41	73
36	91	F	18	0.67	R	3	39	62	32
37	69	M	13	10.33	R	30	56	54	74
38	63	M	12	3.17	L	17	58	54	70
39	70	F	13	3.58	R	2	43	39	44
40	59	F	16	9.25	R	14	45	39	90
41	65	M	13	0.83	R	50	58	54	92
42	56	F	12	2.08	R	46	50	50	80
43	77	F	16	14.75	R	11	50	62	69
44	74	M	16	2.75	R	1	38	41	36
45	64	M	19	2.17	R	38	52	50	84
46	55	M	15	1.58	R	54	63	50	118
47	75	F	12	14.08	R	1	52	50	44
48	77	M	18	11	R	1	47	54	53
49	55	M	16	1.5	R	47	57	62	111
50	66	M	16	1	R	52	56	62	99
51	68	F	18	1.83	R	11	41	16	58
52	62	M	18	6.17	R	17	39	16	100
53	58	M	12	1.83	R	28	56	54	87
54	44	F	16	1.58	L	0	39	47	44
55	79	F	14	9.25	R	47	55	35	96
56	75	M	20	0.5	R	36	46	54	102
57	47	M	11	1.83	R	7	48	62	69
58	55	M	16	1.17	R	52	65	62	117
AVE	**63.4**		**15.2**	**4.1**		**25.0**	**50.3**	**50.9**	**77.6**
SD	**12.3**		**2.8**	**4.2**		**19.6**	**7.3**	**12.5**	**25.6**

Note: AVE = average; SD = standard deviation; M = male; F = female; BNT = Boston Naming Test; CAT Memory = Comprehensive Aphasia Test Memory Composite Score (Semantic Memory + Recognition Memory); SAPA = Standardized Assessment of Phonology in Aphasia

25/60) and language comprehension *t*-score per Comprehensive Aphasia Test (PMT = 50.4; SFA = 50.3). Regarding semantic and phonological processing abilities at pre-treatment, independent samples t-tests confirmed no statistically significant differences between the treatment groups on the CAT memory subtests, $t\ (56) = 1.711$, $p = .093$, which assess picture association and recall or on the SAPA, $t\ (56) = .434$, $p = .666$, which assesses phonological awareness and manipulation.

Treatment Administration

Participants were randomized in pairs so that one participant received SFA and one received PMT. Treatment was administered by a licensed and certified research SLP, and all participants received 56-60 hours of treatment. Treatment was delivered for a total of 8-10 hours/week over 6-7 weeks. Each participant was seen for approximately two hours of therapy per day (two 45-50 minute sessions with a 10-minute break between sessions).

Treatment fidelity was monitored by trained graduate students who evaluated ten-minute, randomly selected audio samples that were recorded one day each week. For each treatment, the evaluator used a checklist (see Supplemental material) of critical treatment components while listening to the recordings to verify if these components were present. A score of 1 was given for each observable key treatment component. A score of 0 was given if a key element was not observed. The percent of critical treatment elements present in each sample was averaged to calculate treatment fidelity. The average treatment fidelity across weeks and participants was 96.75% for PMT and 99.51% for SFA.

Treatment Procedures

PMT aims to strengthen the phonological system and begins by training each phoneme in the English language in a multi-modal manner by training the auditory, motor, tactile-kinesthetic, visual, and orthographic representation for each consonant and vowel. Then phonemes are practiced in nonword sequences (e.g., "eep," "chane") to reduce semantic input before real word phonologic sequences are trained. Through various phonological awareness tasks, participants work on identifying, repeating, parsing, blending, and manipulating the phonemes that compose the nonword and real word trained stimuli. To remain exclusively focused on phonology, pictures and definitions of the trained stimuli are never shown or discussed during therapy. The PMT protocol is detailed in Appendix A and further described in Brookshire et al. (2014) and Kendall et al. (2019). Additionally, PMT resources, such as a procedural manual and treatment materials, are available on the University of Washington Aphasia Research Laboratory website: https://sphsc.washington.edu/research-labs/aphasia-research-lab/professionals .

SFA aims to strengthen the lexical-semantic system and involves teaching the participant to generate descriptions of features (e.g., group, description, function, context, other/personal) of a pictured object in an effort to access that lexical item. The SFA protocol that was implemented in this study is described in detail in Appendix B and further described in Kendall et al. (2019). It is important to highlight that the therapist wrote out the generated semantic features on a white board, and therefore reading was implicitly targeted during treatment.

Treatment stimuli

PMT stimuli were the same as those described in previous studies (Brookshire et al., 2014; Kendall et al., 2015; Kendall et al., 2019) and consisted of 39 real words and 69 nonwords. These words were phonotactically-legal one and two-syllable words of low phonotactic probability and high neighborhood density. These stimuli were selected based on work from Storkel, Armbruster, and Hogan (2006) that showed greater learning occurred with words characterized by these phonological sequence properties. A list of the PMT stimuli can be found in the Kendall et al. (2015) study and online at https://sphsc.washington.edu/research-labs/aphasia-research-lab/professionals .

SFA treatment stimuli consisted of 80 highly imageable nouns from the following eight semantic categories: body parts, clothing and accessories, food and beverages, household, hobbies, recreation/sports, nature, occupations, and transportation. Participants were given either a high- or low-frequency word set based on naming performance during the week of testing before treatment. Of the nouns in each semantic category, ten from each frequency set (high or low) were chosen for training, and five were withheld to assess generalization to untrained items. A list of the SFA stimuli can be found in the Kendall et al. (2019) study.

Reading Outcome Measures

Given the retrospective nature of this study, available reading performance data collected for the main study (Kendall et al, 2019) were analyzed in this work. Table 3 lists those standardized reading measures that were administered one time at pre-treatment, immediate post-treatment, and at 3-month maintenance testing. Oral reading of regularly spelled words (e.g., sheep), irregularly spelled words (e.g., chef), and nonwords (e.g., flig) was assessed using Subtests 35 and 36 from the Psycholinguistic Assessment of Language Processing in Aphasia (PALPA; Kay et al., 1992) and Subtest 1 from the Standardized Assessment of Phonology in Aphasia (SAPA; Kendall et al., 2010). In the reading and alexia literature, it is common practice to assess oral reading of these three word types (Leff & Starrfelt, 2014). Reading performance on these word types is thought to give insight into how the reading network is functioning or malfunctioning. From a PDP point of view, reading of regularly spelled words is proposed to benefit from both orthographic-phonologic and orthographic-semantic knowledge. Irregular word reading is thought to rely more on semantic input to orthography, while nonword reading requires mostly phonological contribution to orthography.

Table 3. Reading Outcome Measures

Reading Stimuli	Test Derived From (Max Score)
Oral Reading	
Regularly spelled words	PALPA 35 and SAPA (51)
Irregularly spelled words	PALPA 35 and SAPA (41)
Nonwords	PALPA 36 and SAPA (36)
Silent Reading Comprehension	
Single words	CAT 8: Written word-to-picture match (30)
	PALPA 50: Written synonym judgment (60)
Sentences	CAT 10: Written sentence-to-picture match (32)

PALPA = Psycholinguistic Assessment of Language Processing in Aphasia (Kay et al., 1992);
SAPA = Standardized Assessment of Phonology in Aphasia (Kendall et al., 2010);
CAT =Comprehensive Aphasia Test (Swinburn et al., 2004)

Regarding assessment of reading comprehension, comprehension of single words was assessed via written synonym judgement (e.g., ocean-sea) (PALPA Subtest 50; Kay et al, 1991) and written word-picture matching (CAT Subtest 8; Swinburn et al., 2004). Sentence-level reading comprehension was assessed by CAT Subtest 10, a written sentence-picture matching task. These reading comprehension measures provide an arguably more functional, real-world assessment of reading ability than oral reading on its own. Participant responses on all reading tests were recorded in real time by the examiner.

Independent *t*-test analyses confirmed that prior to treatment the PMT and SFA groups did not statistically differ on oral reading of regularly spelled words, t (56) = .152, p = .880, irregularly spelled words, t (56) = .600, p = .551, or nonwords, t (56) = .069, p = .946. Independent t-tests also showed the regular and irregular word stimuli did not statistically differ regarding imageability, t (90) = .1.372, p = .188, frequency, t (119) = .514, p = .608, or number of letters, t (126) = .151, p = .880. It should be noted that imageability and frequency ratings were available for most, but not all of the regular and irregular word stimuli. Similar to oral reading, the treatment groups did not differ on the reading comprehension measures before treatment. Specifically, there were no statistically differences in written word to picture match on CAT 8, t (56) = .269, p = .789, written synonym judgement on PALPA 50, t (56) = .200, p = .842, or written sentence to picture match on CAT 10, t (56) = .583, p = .562.

Statistical Analysis

The statistical analyses employed are described per research question below. The Statistical Package for Social Sciences, Version 23.0 (SPSS Inc., 2008) was used to complete these analyses.

To address research question 1 and determine within-in group generalization effects on reading over the course of treatment, one-way repeated measures analyses of variance (ANOVAs) were carried out with testing period (pre, post, follow-up) as the within-subjects factor for each reading measure (i.e., regular words, irregular words, nonwords, word-picture match, synonym judgment, and sentence-picture match) for each treatment group (PMT and SFA) for a total of 12 one-way ANOVAS (six per treatment group).

To address research question 2 and determine between-group generalization effects on reading over the course of treatment, two-way mixed ANOVAs were conducted with group (PMT/SFA) as the between-subjects factor and testing period (pre-, post-, follow-up) as the within-subjects factor for each reading measure (i.e, regular words, irregular words, nonwords, word-picture match, synonym judgment, and sentence-picture match) for a total of 6 two-way ANOVAs.

For all ANOVAs, Mauchly's test of sphericity was run to determine if the assumption of sphericity was met. In the event this assumption was violated, Greenhouse-Geisser values, which adjust the degrees of freedom, were reported instead of the standard statistics.

For all analyses, an alpha value of 0.05 (two-tailed tests) was used to indicate statistical significance. It should be noted within each ANOVA performed, Bonferonni adjustments were made accordingly for planned pairwise comparisons; however no p-value corrections were made for overall total number of ANOVAs. The reader may choose to interpret the results cautiously given the multiple comparisons. It is becoming more common not to correct for multiple comparisons (Lieberman & Cunningham, 2009), especially for studies similar to the current work with a priori comparisons and a small sample size (Ash et al., 2011; Kendall et al., 2019; Madden et al., 2018; Minkina, Martin, Spencer, & Kendall, 2018). The decision not to correct for multiple comparisons is an attempt to balance the probability of making type I and type II errors given the probability of making a type I error is smaller for a priori than post-hoc multiple comparisons and the likelihood of making a type II error is inflated when correcting for multiple comparisons (Ash et al., 2011; Lieberman & Cunningham, 2009; Perneger, 1998).

Results

Table 4 illustrates oral reading performance and Table 5 illustrates reading comprehension performance for both groups across the three assessment time periods.

Within-Group Findings: PMT. Regarding treatment generalization within the PMT group, regular word oral reading was statistically significantly different across the assessment periods, F (1.55, 41.92) = 6.03, p = .009, partial η^2 = .18. Planned pairwise comparisons revealed regular word reading at immediate post-treatment was statistically significantly different from pre-treatment with an average of 3.57 more regular words correct immediately post-treatment compared to pre-treatment (p = .015). Although not significant, an average of 2.18 more regular words were correct at 3 month follow up compared to pre-treatment (p =.217) . Irregular word oral reading was also statistically significantly different across testing times, F (2, 54) = 5.42, p =

Table 4. Average Oral Reading Raw Score Per Treatment Group

Group	Average Oral Reading Performance								
	Regular Words (max score 51)			**Irregular Words (max score 41)**			**Nonwords (max score 36)**		
	Pre	Post	Follow up	Pre	Post	Follow up	Pre	Post	Follow up
PMT	26.50 (18.01)	30.07 (17.14)	28.68 (17.54)	19.32 (13.60)	21.71 (13.55)	21.96 (13.81)	8.07 (9.25)	9.39 (9.17)	9.29 (9.27)
SFA	28.17 (18.22)	31.41 (17.92)	30.62 (18.16)	22.34 (14.89)	23.62 (14.04)	22.92 (14.50)	8.17 (9.80)	8.62 (10.09)	8.62 (10.36)

Note: standard deviation shown in parentheses

Table 5. Average Silent Reading Comprehension Raw Score Per Treatment Group

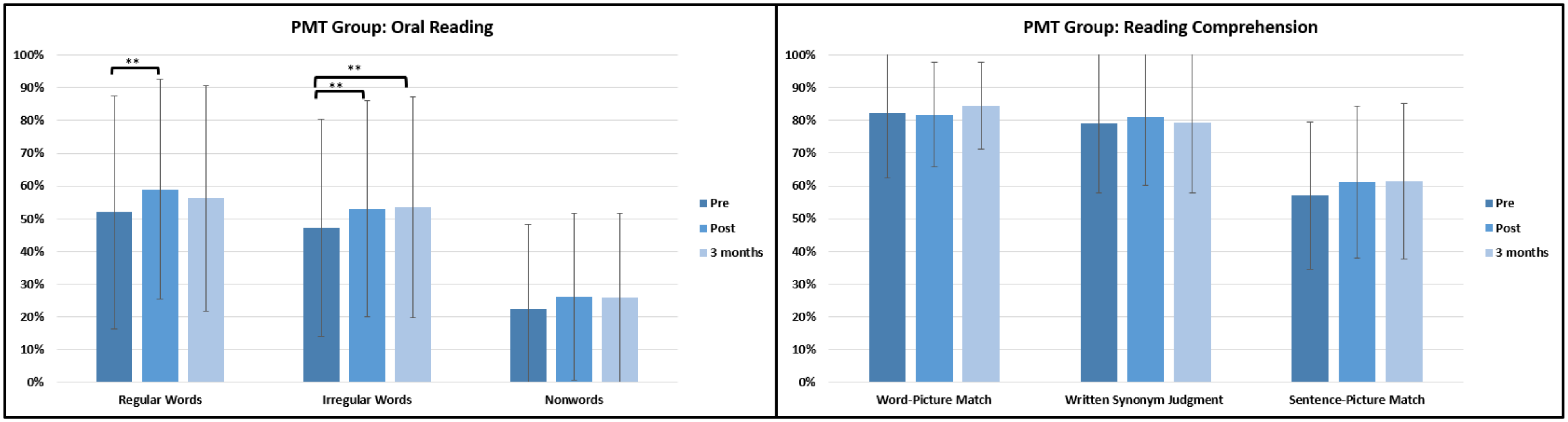
Group	Reading Comprehension								
	Written Word-Picture Match (max score 30)			**Written Synonym Judgment (max score 60)**			**Written Sentence-Picture Match (max score 32)**		
	Pre	Post	Follow up	Pre	Post	Follow up	Pre	Post	Follow up
PMT	24.68 (5.96)	24.54 (4.82)	25.32 (3.98)	47.81 (12.88)	50.27 (8.29)	49.73 (8.96)	18.29 (7.19)	19.61 (7.43)	19.68 (7.62)
SFA	25.35 (4.25)	25.83 (4.25)	25.55 (3.61)	48.89 (6.20)	49.79 (7.01)	49.71 (7.01)	19.70 (6.14)	21.27 (5.81)	21.48 (6.01)

Note: standard deviation shown in parentheses

.007, partial η^2 = .17. Follow-up pairwise comparisons showed significantly better irregular word reading immediately post and 3 months following treatment, with an average of 2.39 more irregular words correct immediately post-treatment (p = .029) and 2.64 more irregular words correct at 3 month follow-up (p = .046) compared to pre-treatment. Changes in nonword reading over the course of treatment approached statistical significance, F (1.501, 40.602) = *2.87,* p = .065, partial η^2 = .096, with an average of 1.32 more nonwords read correctly immediately post-treatment (p =.076) and 1.21 more nonwords read correctly at 3-month follow-up (p =.373**).** Concerning reading comprehension, no statistically significant differences were found for reading comprehension performance on CAT 8: written word-picture match, F (1.121, 32.77) = 2.88, p = .683, partial η^2 = .008, or PALPA 50: written synonym judgment, F *(*1.123, 28.06) = 1.125,/?= .306, partial η^2 = .043. Changes in CAT 10: written sentence-picture match were approaching statistical significance across the testing time points, F (2, 54) = 2.986, p = .059, partial η^2 = .100. Figure 1 illustrates the PMT's group reading performance over time.

Within-Group Findings: SFA. For the SFA group, regular word oral reading was statistically significantly different across the assessment periods, F (2, 56) = 11.90,/? < .001, partial η^2 = .30. Planed pairwise comparisons found statistically better regular word reading immediately post and 3 months post SFA treatment with an average of 3.24 more regular words correct at immediately post-treatment (p < .001) and 2.45 more regular words correct at 3 month follow-up (p = .007) compared to pre-treatment. Across the testing periods, there were no statistically significant differences in irregular word oral reading, F (1.57, 44.06) = *2.69,* p = .090, partial η^2 = .088, or nonword reading, F (2, 56) = 6.00,/? = .553, partial η^2 = .021, for the SFA group. Likewise for single-word reading comprehension, no statistically significant differences were found on CAT 8: written word-picture match, F (2, 56) = .597, p = .531, partial

Figure 1. Phonomotor Treatment (PMT) Group Reading Performance

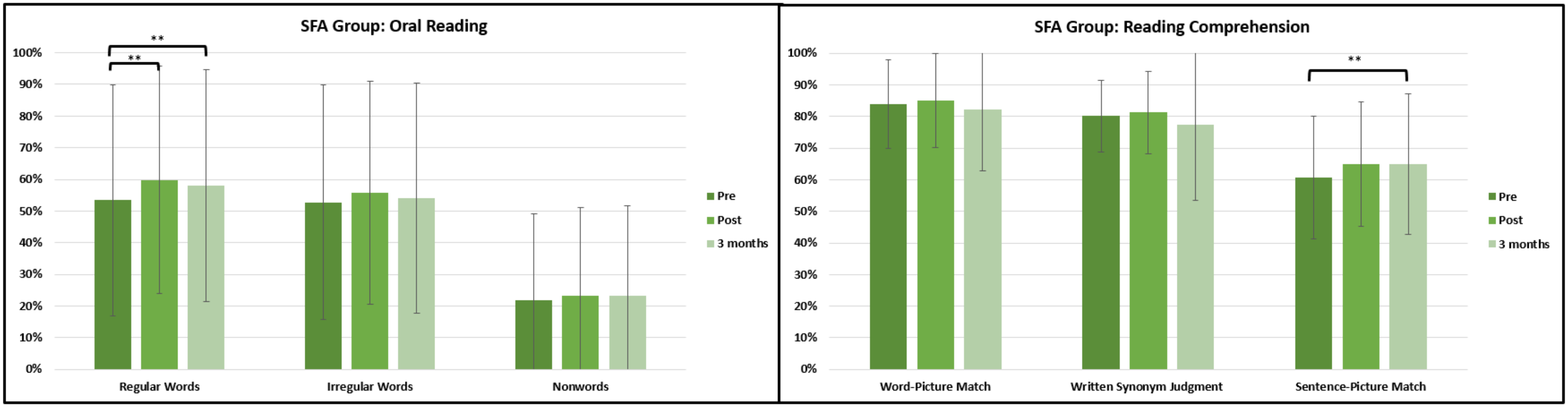


Note: ** = statistically significant difference

η^2 = .021, or PALPA 50: written synonym judgment, F (2, 54) = 8.01,/? = .454, partial η^2 =.029. Comprehension of written sentences on CAT 10 did statistically significantly differ across the time points, F (2, 56) = 4.19, p = .02, partial η^2 = .13, with pairwise comparisons showing an average of 1.79 more sentences correctly read at 3 months post-treatment compared to pre-treatment (p = .03). Interestingly, upon inspection of the treatment stimuli, it was discovered that four words trained in the SFA group were present in the CAT 10 sentences. As a post-hoc analysis, the sentences from the CAT 10 that contained SFA trained stimuli were removed, and there was no longer a statistically significant difference in written sentence comprehension across the testing time points, F (2, 56) = 1.134, p = .329, partial η^2 = .039. No other overlapping between the SFA or PMT trained stimuli and reading assessments were found.

B*etween-Group Findings*. For the 2-way mixed ANOVAs conducted for each oral reading measure, there was no significant interaction between treatment group and testing time (pre, post, or follow-up) period for regular words, F (1.675, 92.141) = .118, p = .855, partial η^2 = .002, irregular words, F (2, 110) = 1.978, p = .143, partial η^2 = .035, or nonwords, F (2, 110) = .764, p = .468, partial η^2 = .014. There was also no main effect of group for regular words, F (1, 55) = .125, p = .725, partial η^2 = .002, irregular words, F (1, 55) = .285, p = .596, partial η^2 = .005, or nonwords, F (1, 55) = .031, p = .861, partial η^2 = .001. A significant main effect of time was present across all participants for all of the oral reading measures. Specifically, regular word reading was statistically significantly different across the time points, F (1.675, 92.141) = 15.762, p < .001, partial η^2 = .223, with an average of 3.41 more regular words correct at immediate post-treatment (p < .001) and 2.31 more regular words correct at 3-month follow-up (p =.004) compared to pre-treatment per pairwise comparisons. Similarly, irregular word reading was also statistically significantly different after treatment, F (2, 110) = 7.489, p = .001, partial

Figure 2. Semantic Feature Analysis (SFA) Group Reading Performance



Note: ** = statistically significant difference

$\eta^2 = .120$, with an average of 1.83 more irregular words correct at post-treatment (p =.004) and 1.62 more irregular words correct at follow-up testing (p =.017) compared to pre-treatment for all participants regardless of treatment group. Nonword reading also significantly changed across the testing time points, F (2, 110) = 3.316, p = .040, partial $\eta^2 = .057$; however, follow up pairwise comparisons were not significant.

Similar to oral reading, for each of the three reading comprehension measures, the 2-way mixed ANOVAS revealed no statistically significant interactions between group and time period for CAT 8: written word-picture match, F (2, 110) = .510, p = .602, partial $\eta^2 = .009$, PALPA 50: written synonym judgement, F (2, 104) = .379, p = .685, partial $\eta^2 = .007$, or CAT 10: written sentence-picture match, F (1.709, 94.003) = .263, p = .735, partial $\eta^2 = .005$. There were also no significant main effects of group for these three reading comprehension measures: CAT 8, F (1, 55) = .027, p = .870, partial $\eta^2 = .000$, PALPA 50, F (1, 52) = .009, p = .926, partial $\eta^2 = .000$, CAT 10, F (1, 55) = .734, p = .395, partial $\eta^2 = .013$. Finally, there was also no significant main effect of time for the two single-word reading comprehension measures: CAT 8, F (2, 110) = 2.41, p = .786, partial $\eta^2 = .004$, and PALPA 50, F (2, 104) = 1.866, p = .160, partial $\eta^2 = .035$. However, CAT 10 showed a significant main effect of time across time points for all participants, F (2, 110) = 7.129, p = .001, partial $\eta^2 = .115$, with an average of 1.454 more written sentences comprehended at immediate post-treatment (p =.01) and 1.593 more sentences correct at 3-month follow-up testing (p =.001), compared to pre-treatment across all participants.

Discussion

This cross-modal investigation was motivated by the primary systems view of language (Patterson & Lambon Ralph, 1999), which proposes that reading performance is dependent on underlying phonological and semantic knowledge. Reading data from an RCT comparing a phonologically-based (PMT) and a semantically-based (SFA) word retrieval therapy (Kendall et al., 2019) were retrospectively analyzed to identify the extent of generalization of anomia treatment to oral reading and reading comprehension performance within and between the two treatment groups.

Overall, the PMT and SFA treatment groups both demonstrated changes in reading performance. Specifically, the PMT group showed statistically significantly improved reading aloud of regularly and irregularly spelled words, and non-word reading gains approached significance. Single word and sentence-level reading comprehension performance improved after PMT, however not to a statistically significant extent. The SFA group made statistically significant gains on oral reading of regular words and sentence-level reading comprehension. Average performance on the other oral reading measures (irregular words and nonwords) and written word comprehension was higher post-treatment, but not statistically significant, for the SFA participants. When comparing reading performance between the two treatment groups, no statistically significant differences were found before or after therapy for oral reading or reading comprehension tasks. These findings are discussed in more detail below.

Interpretation of Within-Group Findings

Phonomotor Treatment. As anticipated, PMT resulted in improved oral reading of regularly spelled and irregularly spelled words. These findings are likely due to the nature of this phonologically-based treatment. PMT aims to strengthen underlying phonological representations and processing (e.g., hearing, saying, seeing, feeling each sound), with an emphasis on phonological-orthographic connections to help individuals with aphasia better identify a phoneme by connecting it to its corresponding letter. PMT's multi-modal approach to the rehabilitation of phonology likely results in stronger phonologic-orthographic connections and therefore may explain the oral reading gains found in this study. Raymer (1993, pg. 50) also found improved oral reading after a phonologically-based anomia treatment and concluded that "improvement of phonological activation could then directly influence graphemic performance."

PMT helps individuals re-learn how letters and sounds relate to one another, and it is logical that improvement of letter-sound correspondence knowledge would be useful when reading regularly spelled words. Additionally, irregular words can also benefit from this knowledge since these words are not completely "irregular" and they contain some typical grapheme-phoneme relationships. We propose that PMT improves phonologic-connections that are needed to read any type of word (nonword, regular, irregular) and this improvement, in conjunction with the reader's semantic-orthographic knowledge, allows for improved reading of irregular words. PMT may give the reader the ability to access some of the phonology of irregular words. Our findings of improved irregular word reading after a phonologically-based treatment support a connectionist model of reading (Plaut, 1996; Plaut et al., 1996) that proposes all written words, regardless of type, are read via one connected language system that relies on learned patterns of connectivity between underlying phonologic, semantic, and orthographic representations.

It was surprising to find that oral reading of nonwords did not reach statistical significance for the PMT group given that PMT involves extensive nonword training and has shown to improve nonword reading in the past (Brookshire et al., 2014). However, those previous nonword findings with eight individuals with phonological alexia may not hold true for this larger, more diverse sample of individuals with aphasia. It is still telling of the potential impact of PMT to influence reading given that reading aloud untrained nonwords was approaching statistical significance post-treatment (p = .065).

Although some PMT participants have shown improved reading comprehension in the past (Conway et al., 1998; Kendall et al., 2003), that was not found at the group level in this study. PMT's focus on phoneme-grapheme knowledge, repetition, and tactile kinesthetic tasks at the single word level, coupled with an absence of semantic input, perhaps make it better suited to improve oral reading skills compared to reading comprehension. Additionally, it is important to note that the single word reading comprehension tasks may have been overly simplistic given some of the participants performed at ceiling before treatment (See Figure 1). This ceiling effect likely hindered accurate identification of any written word comprehension improvement as a result of treatment. Although not statistically significant, it is worth pointing out that performance on sentence-level reading comprehension post-treatment was near significance (p = .06) for the PMT group. This result aligns with a recent finding that phonological skills were predictive of sentence-level (but not word or paragraph) reading comprehension in a group of 43 people with chronic aphasia (Madden et al., 2018).

Semantic Feature Analysis. Within the SFA group, oral reading improvement was limited to regularly spelled words. Lack of improvement on nonword reading was expected; however, it was hypothesized that both regular and irregular word oral reading would improve given that both of these word types can be read via semantic-orthographic knowledge and are not reliant on phonological-orthographic knowledge like nonwords. Both neurologically healthy controls and individuals with aphasia have been shown to read regularly spelled words better than irregularly spelled words (Brookshire, Wilson, Nadeau, Gonzalez-Rothi, & Kendall, 2014), and perhaps this partially explains why the SFA group, which did not have explicit orthographic training like the PMT group, improved the most on the presumably easier of the two types of words.

In addition to improved reading of untrained regularly spelled words, the SFA participants also showed significant improvement on reading comprehension at the sentence level. Interestingly, a post-hoc analysis revealed that four words that were trained during SFA treatment appeared in four of the sentences on the reading comprehension test. When the four sentences with matching stimuli were removed from the analysis, there was no longer a significant improvement in reading performance. Therefore, the reading comprehension generalization for the SFA group might reflect the overlap between some of the words named in therapy and those assessed on the written sentence comprehension test. It is worth noting the syntactic complexity of the deleted items. One removed item had a simpler sentence structure being irreversible and active, which we might expect to benefit more from semantic processing. The other deleted sentences were all more complex being reversible with either a passive structure or embedded clause, which we would expect to rely more on syntactic processing than semantic processing. These post-hoc analysis results should be interpreted cautiously due to the reduced number of items on the reading test after deleting the overlapping items.

The improved reading performance found in the SFA group may surprise some readers, yet it is important to note that SFA implicitly targets reading. In the SFA protocol implemented in this study, and in other SFA studies (Gravier et al., 2018), the semantic features are written down by the clinician, and therefore the participant has constant orthographic input and is continuously reading throughout therapy. For 56-60 hours, the SFA participants viewed numerous written words that comprised the semantic features for each trained word, and this intense exposure to written words, coupled with a presumably strengthened semantic network, likely contributed to enhanced connections between semantics and orthography leading to improved reading. However, had the semantic features not been written down during therapy, generalization to reading is unlikely to have occurred. Similarly, Jacobs and Thompson (2000) found cross-modal generalization of syntax treatment to improved writing of sentences, and these authors raised the point that implicit exposure to written stimuli during treatment likely influenced the treatment generalization findings.

Interpretation of Between-Group Findings

Neither treatment was found to have a superior effect on reading. This lack of statistically significant differences between groups was unexpected and is likely attributable to the high intensity of treatment common to both PMT and SFA treatment groups. Coppens and Patterson (2018) report that longer and more intense treatments are likely to result in greater generalization. Additionally, treatments that are more successful at improving the primary outcome of interest are also more likely to achieve greater generalization compared to treatments with weaker acquisition effects (Coppens & Patterson, 2018). Given that the PMT and SFA procedures were both long and intense and both treatments were successful at improving picture naming for trained and untrained words (the primary outcome of the main study), significant generalization effects could be expected to occur for both treatments. Similarly, in related investigations of noun retrieval (Kendall et al., 2019) and verb retrieval (Lai et al., 2019) involving the same participants as the current study, PMT and SFA also resulted in comparable amounts of generalization with a lack of significant between-group findings. These shared findings might indicate the studies were underpowered, as is most often the case in aphasia research. Alternatively, despite our hypothesis that PMT would have a greater impact on reading, the finding that PMT and SFA both positively influence reading suggests that reading might benefit from intensively delivered phonologically *or* semantically-based treatment approaches for some individuals with aphasia.

Collectively, the positive impact of both SFA and PMT on reading performance supports the Primary Systems notion that enhanced semantic or phonologic processing should lead to enhanced orthographic processing. Additionally, the treatment findings reported here support several previous experimental findings that show semantic and phonologic abilities predict reading abilities in individuals with aphasia (Crisp & Lambon Ralph, 2006; Henry et al., 2012; Madden et al., 2018; Rapcsak et al., 2009).

Clinical Implications

Findings from this work can inform the clinical work of SLPs serving clients with aphasia. Results may encourage SLPs to more closely consider the relationship between spoken and written language and recognize that clients' reading abilities, in addition to naming abilities, may be influenced by intensive anomia treatment. Additionally, this work suggests that acquired reading impairment in individuals with aphasia might be improved by strengthening underlying semantic or phonological networks that support orthographic processing. Therefore, in addition to traditional reading treatment approaches, a focus on underlying semantic and phonological processing skills in clinical practice might also bolster reading skills. Coppens and Patterson (2019) report that treatments targeting an underlying skill as opposed to performance on a finite set of items (e.g., naming ten pictures or reading aloud a list of words) often result in greater generalization. Therefore, a shift in perspective and practice to targeting underlying language mechanisms (e.g., phonology or semantics) as opposed to a language activity (e.g., naming) might lead to greater generalization gains for clients with aphasia.

Limitations and Future Directions

The retrospective nature of this study resulted in limitations in study design and analysis. For example, description of participant reading ability is limited to performance on the reading measures selected for the larger study (Kendall et al., 2019) and future work should expand these reading measures to include a larger number and more diverse stimuli, including paragraph level reading. Additionally, spelling outcome measures should be introduced to fully assess generalization of spoken language treatment to both comprehension and production of written language. The current work reports only on response generalization, as opposed to stimulus generalization, given only reading of untrained stimuli was measured and reading performance on the exact words trained during anomia therapy was not assessed. Therefore, future studies should report reading (and spelling) generalization on both trained and untrained words from anomia treatments to more precisely explain type and degree of generalization and have a better understanding of the treatment effect.

In addition to modifications to the outcome measures, changes to the PMT and SFA protocols can also be made. For example, results of a protocol that more directly targets written language or that combines elements of both PMT and SFA would be interesting to explore and compare to the current findings. Finally, this work is limited to group-level analysis. Individual reading responses were not available, and therefore, it was not possible to characterize alexia type or complete an analysis of reading errors pre- and post-treatment. Future related work would benefit from both group and individual level analysis to help determine which individuals benefit the most and which treatment type, semantic or phonologic, is most appropriate to address both naming and reading impairments. This type of future analysis might include comparing changes in naming accuracy and error type to changes in reading accuracy and error type.

Conclusion

This study provides preliminary evidence that intensive anomia treatment can positively influence reading ability and warrants future investigations of cross-modal language generalization after aphasia treatment. The authors strongly agree with the warning of Webster and colleagues (2015) that studies measuring treatment generalization need a priori hypotheses and should be grounded in theory and evidence to prevent a "fishing" expedition. Careful, well-designed measurement of both targeted and generalized therapy effects should help us realize the comprehensive impact of treatment and contribute to our understanding of the relationship between linguistic levels (words, sentences, paragraphs) and language modalities (speaking, understanding, reading, writing). Results from this initial work support a link between spoken language (word retrieval) and written language (reading) and hopefully encourage further exploration of this relationship and its implication for aphasia rehabilitation.

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Disclosure of Interest

The authors have no financial or non-financial conflicts of interests related to this work.

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Appendix A. Phonomotor Treatment Description and Procedures

Treatment materials	• Small mirror • Line drawings of mouth postures, icons for voiced/voiceless consonants • Letter tiles • Wipe-off board with markers • Small colored blocks	
	Sounds in Isolation	**Sounds in syllables**
Overview	The purpose of Stage 1 is to train sounds in *isolation* through multi-modal instruction using tasks designed to engage distributed articulatory-motor, acoustic, tactile-kinesthetic, and orthographic representations. **Consonant sounds** are introduced using mouth pictures and SLP model as cognate pairs by place/manner of articulation and grouped according to tactile-kinesthetic description (lip, tongue, air, nasal, wind). They are introduced in the following order: lip (*p/b, f/v*), tongue (*t/d, k/g, th/th*), air (*s/z, sh/zh, ch/j*), tongue (*l/r*), nasal (*m/n/ng*) and wind (*h/w/wh*). When mastery of a consonant pair is achieved (e.g. *p/b*) in perception and production (approximately 85% accuracy), the next sound pair is introduced (e.g. *t/d*). Once a sound pair is introduced, training continues on this pair in all subsequent sessions. Once a participant can perceive and produce all consonants in isolation, corresponding graphemes are introduced using the corresponding mouth picture. **Vowel sounds** are trained according to lip and jaw placement via mouth pictures and letter tiles. Vowel sounds (*ee, o, oo*) are introduced with consonants to allow for minimal pair discrimination (e.g., *eep, op, oop*). The remaining vowels are trained after consonants.	The purpose of Stage 2 is to extend skills acquired in Stage 1 to *phoneme sequences*. Treatment tasks remain similar to Stage 1 tasks, with the exception that sounds will be produced in combinations rather than isolation. Training progresses from shorter, monosyllabic sequences to longer, multisyllabic (more complex) sequences (e.g., VC, CV, CVC, CCV, VCC, CCVC, CVCC, CCVCC, CVCV). Both real and nonwords are trained using phonologic tasks (in other words, only phonological features, *not* semantic features, are trained for real words). Nonword training is introduced before real word training to allow for emphasis on phonology; however, as treatment progresses nonwords and real words are trained simultaneously.
Introduction of sounds and sound sequences	Participant observes SLP producing a single sound (e.g. */p/*). SLP asks participant what they observed (heard, saw) and if needed, describes what articulators are moving and how they move. For the sound */p/*, for example, "the lips come together and blow apart, the sound is 'quiet' so the voice is turned off, the tongue is not moving." The participant is then shown the line drawing of the mouth posture corresponding to the sound. After looking at the mouth picture and hearing the SLP's production, the participant is then asked to repeat the sound while looking in the mirror. The participant is also asked to place their hand on their throat in order to feel for vocal fold vibration ("quiet" versus "noisy"). Following production, the SLP asks the participant what s/he saw and felt when the sound was made. Socratic questioning is used to enable the participant to "discover" the auditory, visual, articulatory, and tactile/kinesthetic attributes of the sound (e.g., "What do you feel when you make that sound? What moved? What did you see when you made that sound?" etc.). Within therapy progression for all levels is based on 85% accurate performance on task.	The process of "discovering" sounds primarily occurs in Stage 1; however, knowledge of the auditory, visual, articulatory and tactile/kinesthetic attributes of sounds can also be used later in the program as a cueing technique to identify individual phonemes within a phoneme sequence. For example, if a participant had trouble parsing the initial sound in *peef*, the SLP would use Socratic questioning (e.g., "What do you feel when you make that first sound? What moved? Did your lips or tongue move when you made that sound?" etc.) to help identify the initial sound */p/*. Put differently, rather than give the participant a model and tell them what the initial sound is, the SLP assists the participant in self-awareness of errors and how to repair them.

Perception tasks	Perception of sounds in isolation can be trained through various multi-modal tasks. Examples: • **Mouth pictures:** SLP produces a sound (e.g., *p*) and asks the participant to choose that sound from an array of mouth pictures (e.g., *p, b, t, d*) • **Colored blocks:** SLP produces a string of individual sounds (e.g., *p, t, t, b*) and asks the participant to lay out blocks to demonstrate ability to discriminate sounds (e.g., blocks: red, blue, blue, green). • **Verbal:** SLP produces two sounds (e.g., *p, p* or *p, b*) and asks the participant "same or different." • **Letters:** SLP produces a sound and asks participant to point to the corresponding letter from an array of letters.	The SLP produces a real or nonword sound combination and asks the participant to depict the target through various tasks: • **Mouth pictures:** If the participant heard the CVC *peef*, they would select the pictures corresponding to *p, ee,* and *f.* • **Colored blocks:** If the participant heard the CVCV *peefee*, they would select three differently colored blocks arranged in the following order: white, black, red, black. • **Verbal:** If the participant heard the CCVCs *grook* and *glook*, the SLP would ask "same or different." • **Letters:** If the participant heard *chootee*, s/he would select the corresponding letter tiles.
Production tasks	Production of sounds in isolation can be trained through various tasks. Here are some examples: • **Mouth pictures:** The SLP shows participant a mouth picture and asks the participant to produce that sound (e.g., *d*). • **Motor description:** The SLP describes a sound (e.g., "make the sound where your voice is noisy and your tongue quickly taps the roof of your mouth") and asks the participant to say the sound. • **Verbal:** The SLP asks the participant to repeat a sound *p* or a string of individual sounds *p, p, s, d.* • **Letters:** The SLP shows the participant a letter to elicit production of the sound.	The SLP elicits a real or nonword sound combination by asking the participant to produce the target through various tasks: • **Mouth pictures:** The SLP lays out a series of mouth pictures and asks the participant to "touch and say" each sound (*f-ee-p*) and then blend the sounds to produce the target (*feep*). • **Verbal:** The SLP asks the participant to repeat a nonword *grook* and parse the word apart (*g-r-oo-k*). • **Letters:** The SLP lays out letter tiles (or writes letters on dry erase board). The participant parses out the sounds by underlining and verbalizing each grapheme and then blends the sounds to produce the target.

Note: This appendix has been modified from its original form found in Kendall et al. (2015). Permission to reuse this material has been granted by the American Speech-Language Hearing Association.

Appendix B. Semantic Feature Analysis Treatment Description and Procedures

Treatment materials	• Picture Cards of stimuli • SFA Chart • Wipe-off board with markers and eraser
Overview	Semantic feature analysis is a treatment focused on word retrieval of real words and in this case, nouns. The therapist focuses training by showing a picture (e.g. juice) and asking the participant a series of questions about the semantic features of that noun (e.g. what do you do with it? where do you store it in your home?, etc.). The goal is to strengthen semantic networks within several categories (e.g., food and beverages, household items) and ultimately improve naming ability. A select set of words within each category is trained every session.
Feature Generation	The participant is first asked to verbally name a given picture. Regardless of accuracy, the participant then verbally produces the semantic features of the picture in the context of five categories (see below). The therapist writes the generated features on a whiteboard. Upon completion of the feature generation, the participant is asked to name the picture three times in a row. If named accurately, the therapist will then show a new picture and repeat the same procedures. However, if the participant fails to accurately name the target, the therapist verbalizes the target and asks the participant to repeat the target three times. The therapist then reviews the chart, repeating the target word and one previously generated feature (e.g. 'juice belongs to the group *food and beverages*,' 'juice is a liquid,' etc.). Then the participant is again asked to repeat the target three times. Regardless of accuracy at this stage, the therapist proceeds to the next item.
Semantic Categories	
• Group	The *group* is the semantic category being trained (e.g. *food and beverages, household items*, etc.). The therapist asks, "What group does this belong to?" The participant generates only **one feature** for this category.
• Description	The *description* category explores the inherent properties of the pictured item. The therapist probes, "Let's describe it." The participant is encouraged to explore the color, texture, size, shape, and other associated perceptual characteristics. The participant generates a **minimum of two features** for this category.
• Function	The *function* category presents an opportunity to identify the uses and actions associated to the item. The therapist asks, "What is this used for?" or "What does this do?" The participant generates a **minimum of two features** for this category.
• Context	The *context* category is used to elicit responses related to the location or scene relating to the item. The therapist asks, "Where do you find it?" and "What places or other items are often associated with it?" The participant generates a **minimum of two features** for this category.
• Other/Personal	The *other/personal* category encourages the participant to share their own thoughts and personal stories related to the item. The therapist asks, "What does this remind you of?" or "What does this make you think of?" Only **one personal association** is required for this category.

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