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Research Article

The Influence of Phonomotor Treatment on Word Retrieval Abilities in 26 Individuals With Chronic Aphasia: An Open Trial

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Purpose: The ultimate goal of aphasia therapy should be to achieve gains in function that generalize to untrained exemplars and daily conversation. Anomia is one of the most disabling features of aphasia. The predominantly lexical/semantic approaches used to treat anomia have low potential for generalization due to the orthogonality of semantic and phonologic representations; this has been borne out in a meta-analysis of treatment studies. The intensive, neurally distributed, phonologic therapy reported here can, in principle, generalize to untrained phonologic sequences because of extant regularities in phonologic sequence knowledge and should, in principle, generalize to production of words trained as well as those untrained.

Method: Twenty-six persons with chronic aphasia due to stroke were treated, in a staggered (immediate vs. delayed treatment) open trial design, with 60 hr of intensive, multimodal therapy designed to enhance access to and efficiency of phonemes and phonologic sequences.

Results: There was an absolute increase of 5% in confrontation naming of "untrained" nouns at 3 months, and there were 9% to 10% increases on measures of generalization of phonologic processes.

Conclusion: The results of this trial demonstrate generalization of training effects on laboratory measures, which were sustained at 3 months, and provide support for the theories that motivated the treatment.

Anomia, difficulty retrieving nouns, verbs, and other content words, is one of the most common and disabling aspects of aphasia. Anomia can be caused by damage to the perisylvian substrate for phonemes and phonologic sequence knowledge (Nadeau, 2001); damage to the substrate for meaning (semantics; Rogers, Ivanoiu, Patterson, & Hodges, 2006), which includes association cortices throughout the dominant and, to a substantial extent, the nondominant hemisphere; or damage to long white matter connections linking association cortices to the dominant perisylvian region (Alexander, Hiltbrunner, & Fischer, 1989)—the substrate for what is commonly understood as lexical knowledge. Most often it will be caused by all three.

Typical restitutive approaches to remediating anomia use tasks such as confrontation naming, repetition, orthographic and phonologic cueing, and picture matching using auditory or written words. The stimuli used in these treatments are usually real words (nouns or verbs). These traditional aphasia therapies have been shown to improve naming performance. However, generalization is typically limited; that is, the knowledge gained by the patient tends to be limited to the words actually trained, and there is, at best, modest improvement in naming performance with untrained words (Edmonds, Nadeau, & Kiran, 2009; McNeil et al., 1997; Nickels, 2002). The effectiveness of these treatment approaches has been assessed in a meta-analysis of 44 studies of word-finding treatment for individuals with aphasia who were more than 6 months poststroke. Treatment effects were seen for trained and exposed words (effect size [ES] = 2.66), with much less improvement for untrained words (ES = 0.44; Wisenburn & Mahoney, 2009). The ES for trained words declined only modestly over 3 months of follow-up, but the ES for "untrained" words fell sharply, leading to a global 3-month ES of 0.48. No treatment (semantic, phonologic, or mixed) clearly emerged as superior.

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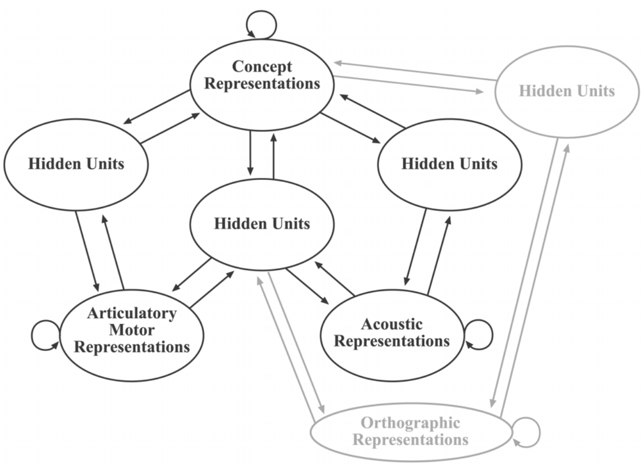
Ideally, the overarching goal of anomia therapy is to improve production of words that were trained in therapy, maintain these changes over time, and achieve sustained generalization to untrained words and daily conversation. The potential for generalization using current therapy techniques is bound to be modest unless the brain mechanisms underlying intrinsic generalization can be better engaged, enabling treatment to have a broader effect on lexical retrieval for all items, rather than just those that have been trained. Broad intrinsic generalization is a challenge for lexical therapies because their principal aim is to reestablish connections between semantic and phonologic substrates for single items, one item at a time. Because word meaning and word sound are substantially unrelated (with the exception of onomatopoeic words and derivational forms), there are few regularities underlying lexical knowledge, and learning to produce one word is unlikely to benefit production of another. Semantic therapies can achieve generalization by further capitalizing on regularities in semantic knowledge. For example, by taking advantage of the fact that animals share many features, training on some animals can facilitate verbalization of names of untrained animals. Knowledge of particular semantic domains might usefully be fleshed out in this way. However, it is difficult to develop semantic knowledge that spans the breadth of daily life one semantic domain at a time. New approaches that circumvent this domain limitation are being developed and show considerable promise (Edmonds & Babb, 2011; Silkes, Dierkes, & Kendall, 2012). Thus, the generalizing possibilities of semantic therapies are only beginning to be explored.

The other major knowledge domain relevant to naming (phonology) also has extensive intrinsic regularities, enabling broad enhancement of phonologic knowledge by training a subset of phonemes and phonologic sequences. Furthermore, because all words in a language make use of the same phonologic sequence repertoire, phonologic therapy has the potential for broad generalization to all words. Every language uses a limited repertoire of phoneme sequences, reflected in such measures as biphone probabilities. Neural network simulations, particularly those using recurrent networks, have clearly shown the capacity for simple networks to acquire specific sequence knowledge (see Nadeau, 2012, for review) and are best exemplified in the work of Plaut, McClelland, Seidenberg, and Patterson (1996). We have been developing and testing a phonologic sequence-based therapy, called phonomotor treatment, that is unprecedented in its systematicity and dose (Kendall, Conway, Rosenbek, & Gonzalez-Rothi, 2003; Kendall, Nadeau, et al., 2006; Kendall, Rodriguez, Rosenbek, Conway, & Gonzalez-Rothi, 2006; Kendall et al., 2008; Raymer, Haley, & Kendall, 2002). We present here the results of our largest trial of the most refined version of this therapy.

The phonomotor treatment is inspired by a parallel distributed processing (PDP) model of lexical processing (Nadeau, 2001, 2012; Roth, Nadeau, Hollingsworth, Cimino-Knight, & Heilman, 2006; see Figure 1) and the Lindamood Phoneme Sequencing Program (Lindamood & Lindamood, 1998; see Kendall et al., 2008, for extensive overview). In this PDP model-driven approach to treatment of phonologic dysfunction, we assume a diminished representation and processing of individual phonemes and phoneme sequences because of the loss of dominant perisylvian synapses caused by stroke, compensated to some extent by redundant but poorly developed phonologic sequence knowledge in the nondominant hemisphere. We also assume residual lexical semantic knowledge in one or both hemispheres that is instantiated in connections between association cortices (which support semantic representations; Forde & Humphreys, 1999; Nadeau, 2012; Warrington & McCarthy, 1987; Warrington & Shallice, 1984) and perisylvian cortices (which support phonologic sequence knowledge; Nadeau, 2001).

Figure 1. Proposed parallel distributed processing model of language. Each oval should be interpreted as a large number of units, each unit connected to every unit in each connected oval. Knowledge is represented as the strength of connections between units. Connectivity within the substrate for concept representations defines semantic knowledge. Connectivity within the perisylvian acoustic–articulatory motor pattern associator network defines phonologic sequence knowledge. Connectivity between the substrate for concept representations and the acoustic–articulatory motor pattern associator defines lexical knowledge (the phonologic output lexicon). Unit activity, defined as a nonlinear sigmoid function of input to a given unit, spreads along connections to other units. Given a particular input to any part of the model, activity spreads and unit activity auto-adjusts until the model settles into a state that is optimal given the strengths of the various inputs and connectivity patterns within the network (see Nadeau, 2001, 2012; Roth et al., 2006). The points of articulation of orthographic representations and this core model are approximate but capture the well-established existence of semantic and phonologic routes for reading aloud and provide an explanation for the potential role of orthographic input in phonomotor treatment. The aggregate model provides an explanation for how phonologic (acoustic) input, orthographic input, and conceptual input (e.g., “a lip popper,” the patient’s image in a mirror while producing a labial stop, a picture of a sagittal slice through the midline oropharynx during production of a labial stop) are brought to bear on phoneme and phonologic sequence knowledge.



The hypothesis motivating our treatment is that through intensive, neurally distributed, multimodal (auditory, motor, orthographic, tactile–kinesthetic, and conceptual) training of phonemes and one-, two- and three-syllable real and nonword phoneme sequences, the neural connectivity supporting phoneme sequence knowledge can be enhanced. Because this distributed phonologic knowledge provides the basis for the articulatory forms of all words, enhancing it can be expected to improve naming of untrained words and discourse production. These hypotheses seem plausible because there is no evidence that brain damage of any type alters the fundamental principles of brain operation, which emerge from the organization of neural networks and neural systems. Also, the hypotheses are predicated upon the existence, in damaged form, of exactly the same networks that enabled these participants to acquire language in the first place. Phonomotor treatment was founded on these hypotheses, and we have shown that, when intensively delivered, confrontation naming performance on trained real words and nonwords improves. In addition, we have shown that there is generalization to naming of untrained words, some aspects of discourse production, and indicators of quality of life (Kendall et al., 2003; Kendall, Nadeau, et al., 2006; Kendall et al., 2008; Raymer, Haley, & Kendall, 2002).

The objective of the current investigation was to continue the development of this Phase II phonomotor treatment protocol under the rubric of clinical phases of rehabilitation research (Robey, 2004). More specifically, this study was designed to extend prior iterations of the treatment protocol and test a refined version in a relatively large group of persons with aphasia (PWA) who exhibited impairments of lexical/semantics and phonology resulting in anomia. In contrast to Kendall et al. (2008), the current investigation used the following: (a) a random assignment to either immediate or delayed treatment groups to control for improvement of language abilities from passage of time and any improvement that may be related to exposure to the outcome measures, (b) a real word and nonword stimuli of low phonotactic probability and high neighborhood density to improve treatment efficiency, (c) a reduction of treatment dosage from 96 to 60 hr (on the basis of the existing unpublished data that treatment effects appeared to reach a plateau at 60 hr), and (d) a standardized impairment level measure of phonologic processes and measures of ecologic validity.

The purpose of introducing real words into the training program was to add top–down input from semantic representations to bottom–up input of phonologic sequences, thereby engaging Hebbian learning mechanisms to help to encode phonologic sequence knowledge in neural connectivity. We view this only as a potential adjuvant to the intensive phonologic sequence training that is the essential element of our phonomotor therapy. Absent sequence training, real word training becomes just lexical training, with its theoretical and empirical shortcomings, as discussed. Low phonotactic probability stimuli were used to capitalize on the use of atypical exemplars to facilitate generalization. Prior studies, also on the basis of a PDP model of lexical semantics (Plaut, 1996), have shown that treatment of atypical exemplars can improve performance with both typical and atypical exemplars, whereas treatment limited to typical exemplars benefits performance only with typical exemplars. This has been demonstrated in lexical semantic treatment of patients with anomia due to aphasia (Kiran & Thompson, 2003) and in syntactic treatment of patients with agrammatism (Thompson, Shapiro, Kiran, & Sobecks, 2003). The phenomenon is related to the fact that training of atypical exemplars directly benefits those items but also indirectly benefits typical exemplars that share some features. However, training of typical exemplars alone cannot capture the features that uniquely characterize atypical exemplars. Storkel, Armbrüster, and Hogan (2006) have provided empirical support for this concept with typical adults in the domain of phonology. We used phonemes and phoneme sequences with high neighborhood densities because we wanted to take maximum advantage of remnant connections between substrates for phonologic and semantic knowledge.

The difference between our treatment and other semantic–phonologic treatments is one of degree. Other semantic–phonologic treatments potentially strengthen phonologic sequence knowledge predominantly through induction of Hebbian learning within the phonologic sequence domain. Our treatment uses training of individual phonemes and phoneme sequences that is unprecedented in its systematicity and its dose. Further, unlike other phonologic treatments, the phonomotor treatment is based on the notion of distributed (auditory, articulatory, orthographic, visual) phonologic representations, which, when refined through training, improve phonologic awareness. Hebbian learning achieved through introduction of real words into the training algorithm and therefore serves only as an adjuvant to our core training procedures.

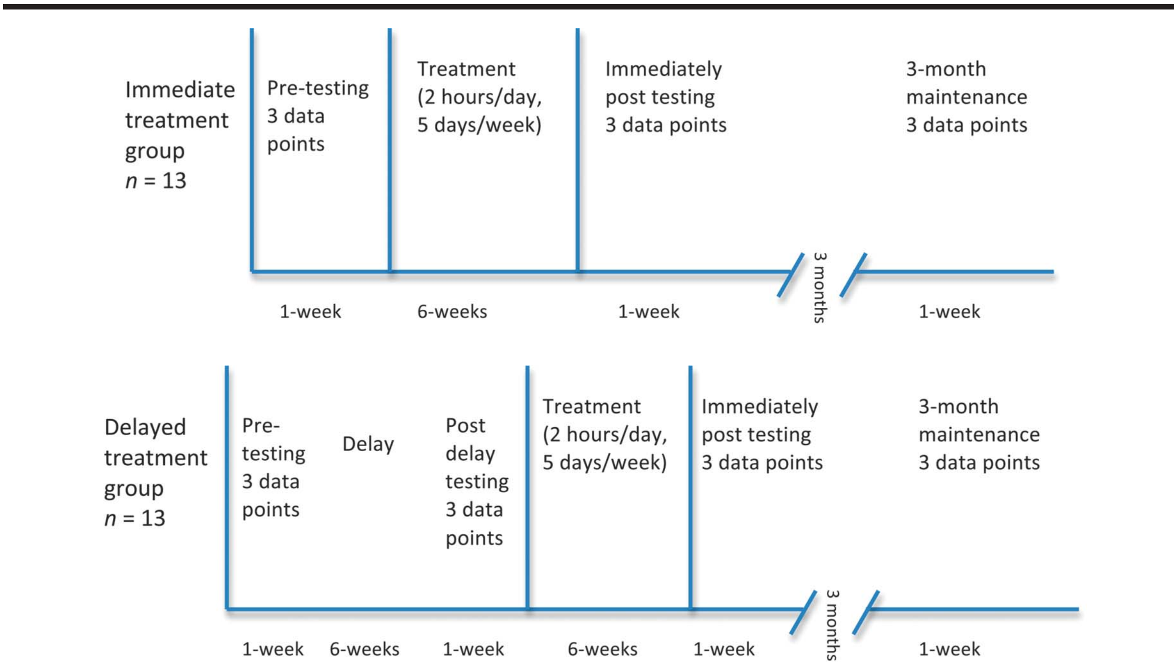
The primary outcome measure of this study was verbal confrontation naming of "untrained" nouns at 3 months after treatment termination. Our primary outcome measure, then, measured both generalization to untrained items and long-term retention of generalized knowledge gained in therapy. Secondary outcome measures assessed the following: (a) acquisition of trained items (confrontation naming of nouns and nonword repetition), (b) generalization to phonologic processes as measured by performance on the Standardized Assessment of Phonology in Aphasia (SAPA; Kendall et al., 2010) and untrained nonword repetition, (c) generalization to two measures of ecologic validity (self-report and caregiver report), and (d) maintenance of performance at 3 months on all measures.

Method

Study Design

The study design was a single group (n = 26) with repeated testing. All participants received the same treatment protocol (described in detail in the Appendix). In order to control for improvement in language function related to passage of time and for the effect of repeated exposure to outcome measures, individuals were randomly assigned to one of the two conditions: delayed treatment or immediate treatment (see Figure 2). Participants who were

Figure 2. Study design.



randomized to the delayed group received repeated testing three times before and three times after a 6-week delay. During the delay phase, they were permitted to participate in usual speech-language care (e.g., conversation groups and individual therapy). Standardized assessments and outcome measures (described in detail below) were administered prior to the start of treatment (for both immediate and delayed groups), at the end of the delay phase (delayed group only), immediately after treatment termination, and at 3 months posttreatment.

Participants

Participants were recruited through the Veterans Affairs Medical Center Puget Sound and the University of Washington Aphasia Registry and Repository. Twenty-eight persons were recruited, all with chronic aphasia 6 or more months after left hemisphere damage due to a single stroke (documented by computed tomography or magnetic resonance imaging scan and/or report). To be included in the study, participants had to have demonstrated aphasia with anomia and impairment of phonology. Presence of aphasia was defined using the criteria of McNeil and Pratt (2001), and severity was determined using the Western Aphasia Battery Aphasia Quotient (WAB-AQ; Kertesz, 1982). Presence and severity of phonologic impairment were determined by performance on the SAPA (Kendall et al., 2010). Severity of anomia was determined by performance on the Boston Naming Test (BNT; Kaplan, Goodglass, Weintraub, & Segal, 1983). Testing was administered by certified speech-language pathologists (SLPs; first three authors of this article), who were trained in protocol administration.

Individuals were excluded if they exhibited severe apraxia of speech, which was determined by three SLPs using data from the evaluation. Apraxia of speech was defined by a slowed speaking rate (prolonged sounds and/or intersegment durations); distortions or distorted substitutions; and prosodic abnormalities during discourse production, repetition of words and nonwords, and naming tasks. Additional exclusion criteria included major depressive disorder or other psychiatric illness, degenerative neurologic disease, chronic medical illness, or severe and/or uncorrected impairment in vision or hearing.

Two individuals were excluded during the course of the trial. One individual exhibited significant unilateral upper motor neuron dysarthria that was found to preclude reliable scoring of the outcome measure data. The second person was excluded near completion of the treatment protocol after receiving a diagnosis of ongoing and undetected seizure activity. Of the 26 individuals who completed the treatment protocol, all returned for 3-month posttesting.

The 26 PWA were, on average, 56 years of age (*SD* = 15), had 16 years of education (*SD* = 3), and were—on average—48 months poststroke onset (*SD* = 53). There were 15 men and 11 women. Twenty-four individuals were monolingual English, and two were bilingual but proficient in English. During the screening process, bilingual participants were interviewed with respect to the age of acquisition of English and which language they used most at the time of stroke. Language preference was confirmed by an individual who had known the participant for more than 1 year prior to the stroke who agreed that (a) English was the preferred language and (b) English was the predominant language spoken by the participant at the time of the stroke (see Table 1).

The group mean aphasia quotient on the WAB-AQ (Kertesz, 1982) was 78.67/100 (±16.5); mean score on the BNT (Kaplan et al., 1983) was 34/60 (±18); and mean score on the SAPA (Kendall et al., 2010) was 95.8/151 (±24.1).

Treatment Procedure

This study investigated how lexical retrieval abilities were influenced by an intensively delivered, explicit, multimodal (orthographic, auditory, articulatory–motor, tactile–kinesthetic, visual, and conceptual), phonologic-based treatment using phonemes in isolation and one-, two-, and three-syllable phoneme sequences in real word and nonword combinations. All participants received 60 hr of phonomotor treatment (1-hr treatment sessions, two consecutive sessions/day, 5 days/week for 6 weeks) provided by three certified research SLPs (first three authors of this article).

The research SLPs received training on the treatment protocol by the first author. Following training, they delivered 60 hr of treatment tasks across all treatment levels to an individual with aphasia under supervision by the first author. The first author observed both SLPs performing therapy to ensure that they demonstrated an adequate level of performance and that their treatment techniques were equivalent. To ensure treatment integrity across participants throughout the length of the study, the SLP administering treatment was randomly observed by one of the other two SLPs for approximately 10% of each participant's treatment program. The first author and research SLPs met weekly to review any issues related to treatment delivery and participant performance. The treatment program is outlined in detail in the Appendix.

Treatment Stimuli

The stimuli were comprised of phonemes in isolation and one-, two-, and three-syllable phoneme sequences in real and nonword combinations consisting of phonologic sequences of low phonotactic probability (PP) and high neighborhood density (ND). This approach was based on work by Storkel et al. (2006) in which they differentiated effects of phonotactic probability and neighborhood density on adult word learning in 32 normal controls. Their results indicated that rarer sound sequences (low PP) triggered learning more efficiently than more common sound sequences (high PP; consistent with the results of Kiran & Thompson, 2003; Plaut, 1996; Thompson et al., 2003) and high ND

Table 1. Participant characteristics.

Participant	Age (years)	Sex	Education level (years)	Duration post onset (months)	WAB-AQ (out of 100)	BNT (out of 60)	SAPA (number correct out of 151)	Confrontation naming of 83 nouns (% correct)	Repetition of 145 nonwords (% correct)
1	49	M	16	21	87.5	37	96	82	62
2	26	M	16	45	94.2	57	128	90	93
3	48	M	13	16	94.6	52	131	87	97
4	27	M	13	17	51.1	44	74	68	84
5	67	F	14	162	84.5	36	94	85	35
6	53	M	19	81	63.9	13	64	35	60
7	63	M	16	15	37.6	1	53	6	25
8	64	M	20	52	76.3	9	80	31	40
9	57	F	14	38	52.6	5	61	31	74
10	47	F	16	11	84.6	50	123	87	97
11	62	M	15	29	96.1	57	115	92	90
12	74	F	18	8	91.3	51	105	84	85
13	30	F	14	14	50.8	5	50	43	28
14	60	F	18	65	59.5	15	81	40	54
15	57	M	16	24	82.0	31	102	58	84
16	72	M	18	211	69.8	34	76	42	57
17	67	M	16	104	81.1	56	103	83	52
18	68	M	23	14	92.0	57	109	89	64
19	33	F	15	31	78.2	31	65	52	77
20	70	M	16	10	94.7	43	114	76	86
21	45	F	12	14	85.2	22	124	51	97
22	78	M	13	41	90.2	46	105	68	79
23	61	F	16	15	95.0	50	110	89	79
24	67	M	15	20	86.6	18	124	70	98
25	61	F	18	155	92.0	32	109	61	69
26	51	F	13	22	74.3	41	96	79	84
AVE	56		16	48	78.7	34.3	95.8	65.4	72.2
SD	15		3	53	16.5	18.1	24.1	23.8	22.0

Note. WAB-AQ = Western Aphasia Battery Aphasia Quotient; BNT = Boston Naming Test; SAPA = Standardized Assessment of Phonology in Aphasia; M = male; F = female; AVE = average.

enhanced integration of new lexical representations with existing representations.

Eighty-three real words (42 trained and 41 untrained) and 145 nonwords (72 trained and 73 untrained) were created. Phonotactic probability was calculated using methods similar to those of Vitevitch and Luce (1999). All nonwords were phonotactically legal in English. A web-based interface was used to calculate phonotactic probabilities for the real words and nonwords (Vitevitch & Luce, 2004). ND was computed by counting the number of words in the dictionary that differed from the target by a one phoneme addition, deletion, or substitution. Phonotactic probability and neighborhood density were computed for stimuli and were categorized as high or low on the basis of a median split (using procedures similar to those of Storkel et al., 2006). Real word stimuli were created using the MRC Psycholinguistic Database (Coltheart, 1981) to determine written frequency, imageability, age of acquisition, syllable number, syllable complexity, and semantic category. Photographic color pictures representing the real word stimuli were used (see Table 2 for the list of stimuli).

Outcome Measure Administration

Three certified research SLPs (first three authors of this article) and a research assistant (graduate student in speech-language pathology) were trained in the testing protocol that was used for the administration of all outcome measures. Measures were administered on 3 consecutive days immediately prior to the beginning of treatment, on 3 consecutive days immediately after treatment completion, and on 3 consecutive days 3 months following treatment completion. Outcome measure values for each 3-day test sequence were averaged to reduce the effects of test–retest variability on statistical analysis of outcomes. The mean performance for the three time points was used in the statistical analysis.

Outcome Measure Description

The primary outcome measure of this study was accuracy of confrontation naming of "untrained" nouns at 3 months. The stimuli used in this outcome measure have been described in the Treatment Stimuli section.

The secondary outcome measures assessed acquisition, generalization, maintenance, and indicators of quality of life. In order to determine treatment acquisition effects, accuracy data were collected from repetition of trained nonword stimuli and confrontation naming of trained nouns (described in the Treatment Stimuli section). Generalization of treatment effects to phonologic processing abilities was assessed using the SAPA and repetition of untrained nonwords (described in the Treatment Stimuli section).

The SAPA was created as a tool to identify PWA with poor performance on phonologic tasks (relative to other aphasic individuals) who might be potential candidates for phonologic treatment. The tool was also intended to be used to measure severity of a phonologic processing impairment as well as to capture any improvement in phonologic processing as a result of treatment. Item response theory (IRT) informed the development of the SAPA. IRT statistics have been computed in 47 PWA to evaluate psychometric properties of interest. The test demonstrates acceptable construct validity, sensitivity, and test–retest reliability (see Kendall et al., 2010, for details). Continued IRT data analysis for 100 PWA is currently underway.

Finally, in order to determine whether treatment generalized to indicators of quality of life, data were collected using the participant-rated Stroke and Aphasia Quality of Life scale (SAQOL; Hilari & Byng, 2001; communication items only) and the caregiver-rated Functional Outcomes Questionnaire (FOQ; Glueckauf et al., 2003).

Outcome Measure Analysis

Outcome measures were scored online at the time of testing. In addition, verbal responses on most of the outcome measures (except the SAPA, SAQOL, and FOQ) were digitally recorded for subsequent reliability analysis. For the real word confrontation naming data, accuracy was determined at a whole word level and scored as correct or incorrect. Incorrect responses included phonologic and semantic substitutions, additions and deletions, neologisms, and nonresponses. For the nonword repetition data, accuracy was determined at a word level as each word was scored as correct or incorrect. Incorrect responses included phonologic errors (substitutions, omissions, transpositions, anticipations) and nonresponses.

Statistical Analysis

Change scores for the primary and secondary outcome measures administered before treatment, immediately posttreatment, and 3 months posttreatment were analyzed using Student's paired *t*-tests; *p* values were not corrected for multiple comparisons because this study had a single primary outcome measure, and the purpose of all other outcome measures was to elucidate the effects of the therapy. ESs were calculated as mean change/*SD* baseline and interpreted using the 0.2, 0.5, and 0.8 (small, medium, large) benchmarks of Cohen (1998). ESs were calculated for each of the outcome measures and are displayed in Table 3.

Reliability

Point-to-point reliability was performed on 33% of the total corpus of confrontation real word naming and nonword repetition outcome measures. Interclass correlations demonstrated intrarater reliability of .962 (nonword repetition) and .992 (confrontation naming) and interrater reliability of .989 (nonword repetition) and .989 (confrontation naming).

Results

Compliance of therapy completed by participants was 100%. All participants received exactly 60 hr of treatment in

Table 2. Trained and untrained stimuli used in treatment.

Trained sounds in isolation		Real words				Nonwords			
		Trained		Untrained		Trained		Untrained	
IPA symbol	Trained graphemic representation(s)	1 syllable	2 syllables	1 syllable	2 syllables	1 syllable	2 syllables	1 syllable	2 syllables
p	P	ape	feeder	toy	tire	doi (dɔɪ)	chootee (tʃuti)	ain (eɪn)	wurkee (wɝki)
b	B	ache	jockey	age	usher	af (æf)	zhuree (ʒɝi)	poom (pum)	koetoe (koʊtoʊ)
f	F	itch	ivy	eel	wire	toos (tus)	foekoe (foʊkoʊ)	gee (gi)	wayzer (weɪzɚ)
v	V	edge	gravy	whip	iron	sheev (ʃiv)	leber (lɛbɚ)	haje (heɪdʒ)	rooit (ruɪt)
t	T	bow	lasso	beef	baby	ek (ɛk)	doem (doʊʌm)	loy (lɔɪ)	sayvay (seɪveɪ)
d	D	day	tower	birth	valet	dach (dætʃ)	mefoe (mɛfoʊ)	heeg (hig)	fooer (fuɚ)
k	K	hay	shadow	ditch	lady	peenz (pinz)	shever (ʃɛvɚ)	jong (dʒɑŋ)	laybee (leɪbi)
g	G	thigh	shoulder	wheel	chauffeur	poa (poʊə)	feether (fiðɚ)	poy (pɔɪ)	grayzee (greɪzi)
θ	Th	cave	treasure	jeans	laughter	meeth (miθ)	toiler (tɔɪlɚ)	awb (ɑb)	ekee (ɛki)
ð	Th	maze	ladder	pie	turkey	ri (rɪ)	izel (ɑɪzl)	jeef (dʒif)	badow (bædoʊ)
s	S	boot	teacher	fir	fisher	ish (ɪʃ)	shaybee (ʃeɪbi)	tay (teɪ)	nider (nɑɪdɚ)
z	Z	fig	jail	knee	razor	whup (wʌp)	veeder (vidɚ)	mirth (mɝθ)	eepoe (ipoʊ)
ʃ	Sh	bird	jury	egg	clover	breek (brik)	zower (zaʊɚ)	vank (vænk)	vaylow (veɪloʊ)
ʒ	Zh	mop	ranger	rash	fire	voo (vu)	tawthee (tɑθi)	bap (bæp)	sheefur (ʃifɚ)
tʃ	Ch	half	leather	witch	genie	eep (ip)	jiver (dʒɪvɚ)	ka (kæ)	hoower (huwɚ)
dʒ	J	song	diver	knot	halo	reesh (riʃ)	wooter (wutɚ)	ool (ul)	eeshur (iʃɚ)
l	L	knob	lawyer	break	meadow	nie (nɑɪ)	dungee (dʌŋi)	wog (wɑg)	rayger (reɪgɚ)
r	R	gray	level	bride	shower	iej (aɪdʒ)	turmee (tɝmi)	glane (gleɪn)	zopper (zɑpɚ)
h	H	plane	owl	bruise	voter	zine (zɑɪn)	lekzher (lɛkʒɚ)	ieg (ɑɪg)	joah (dʒoʊə)
w	W		father	poem	tiger	broiz (brɔɪz)	lekee (lɛki)	dite (dɑɪt)	tawkee (tɑki)
Wh	wh		heater		speaker	thag (θæg)	juroe (dʒɝo)	grabe (greɪb)	zire (zɑɪər)
m	M		polo			oit (ɔɪt)	shashoe (ʃæsoʊ)	jie (dʒɑɪ)	thiver (θɪvɚ)
n	N		movie			kur (kɝ)	hoyter (hoɪtɚ)	wawj (wɑdʒ)	wiver (wɑɪvɚ)
ŋ	Ng					froos (frus)	neenee (nini)	fie (fɑɪ)	uzher (ʌʒɚ)
i	Ee					grake (greɪk)	rayzel (reɪzl)	oozh (uʒ)	chafter (tʃæftɚ)
ɪ	I					choy (tʃɔɪ)	highger (hɑɪgɚ)	whike (wɑɪk)	osay (oseɪ)
ɛ	E					oos (us)	woewuh (woʊwə)	gride (grɑɪd)	doojee (dudʒi)
eɪ	Ae					wap (wæp)	unger (ʌngɚ)	loich (lɔɪtʃ)	fayshur (feɪʃɚ)
æ	A					faps (fæps)	miver (mɑɪvɚ)	moy (mɔɪ)	shiloe (ʃɪlo)
ʌ, ə	U					woy (wɔɪ)	jawvee (dʒɑvi)	jurl (dʒɝl)	voker (voʊkɚ)
ɑ, ɔ	o, aw					awch (ɑtʃ)	prezhur (prɛʒɚ)	thed (θɛd)	haybee (heɪbi)
o, oʊ	Oe					plown (plaʊn)	foover (fuvɚ)	eem (im)	rieger (rɑɪgɚ)
ʊ	Oo					zae (zeɪ)	pire (pɑɪɚ)	riz (rɪz)	layfee (leɪfi)
u	Oo					hob (hɑb)	dryper (drɑɪpɚ)		meevee (mivi)
ɑɪ	Ie					veed (vid)	gower (gaʊɚ)		tycher (tɑɪtʃɚ)
Ju	Ue						teever (tivɚ)		kloper (kloʊpɚ)
ɔɪ	oi, oy						ibee (ɑɪbi)		nyer (nɑɪɚ)
aʊ	ow, ou								langee (leɪŋi)
ɝ, ɚ	er, ir, ur								gainjer (geɪndʒɚ)
ɔr	Or								skonner (skɑnɚ)
ɑr	Ar								

the course of 6 weeks (2 hr/day, 5 days/week). In the delayed group, no significant difference in accuracy of confrontation naming of nouns for the immediate (pretreatment performance) compared with delayed (postdelay phase performance) group was found (p = .726 trained stimuli, p = .657 untrained stimuli). Therefore, data for all outcome measures for both groups were combined for analysis and interpretation. Specifically, the delayed group performance during confrontation naming of trained stimuli was 65.20 (SD = 15.93) at the predelay phase and 65.20 (SD = 24.02) postdelay (p = .726). The delayed group confrontation naming performance of untrained stimuli at the predelay phase was 66.91 (SD = 18.27) and 65.52 (SD = 23.50) postdelay (p = .657).

An overview of the results is provided here, and details are outlined in the Primary Outcome Results, Secondary Outcome Results, and Standardized Assessment sections. Essentially, treatment was associated with a statistically significant gain in the primary outcome measure (untrained real word naming at 3 months posttreatment; see Table 3 and Figure 3). ES for retention of trained items at 3 months (trained confrontation naming and nonword repetition) fell in the medium to large range. ES for gains in measures of generalization fell into the small to medium range. ES for gains in a standard measure of language function (WAB) was small, and measures of ecologic validity fell in the small to medium range. Individual performance reveals considerable heterogeneity of response (see Figure 4 and Table 4). Approximately 50% of our participants demonstrated evidence of a response to treatment (an absolute gain of ≥3% in untrained real words named), and approximately 33% demonstrated a substantial gain (≥7% absolute gain in untrained real words named).

Table 3. Results.

Research aim	Outcome measures	Pretreatment, mean absolute score, % (*SD*)	Acquisition: % of absolute change, pre versus immediately post (*SD*)	Acquisition: *p*	Acquisition: ES[a]	3-month maintenance: % of absolute change pre versus 3-month post (*SD*)	3-month maintenance: *p*	3-month maintenance: ES[a]
Trained stimuli	Trained nonword repetition	71.55 (20.91)	16.67 (14.03)	.000	.80	13.74 (12.13)	.000	.66
	Trained real word confrontation naming	65.20 (24.02)	18.16 (13.06)	.000	.76	13.17 (11.40)	.000	.55
Generalization, phonologic processes	SAPA (raw score/151)	65.36 (25.67)	9.53 (9.91)	.000	.37	8.96 (8.33)	.000	.35
	Untrained nonword repetition	72.80 (23.07)	10.74 (11.49)	.000	.46	9.83 (10.84)	.000	.43
Generalization, lexical/semantics	Untrained real word confrontation naming	65.52 (23.50)	5.27 (8.09)	.003	.22	5.28 (7.55)	.002[b]	.22
Ecologic validity	FOQ	4.08 (0.606)	0.23 (0.47)	.023	.39	0.22 (0.53)	.069	.36
	SAQOL	3.34 (0.71)	0.33 (0.68)	.021	.46	0.34 (0.71)	.030	.48
Standardized assessments	BNT	34.34 (18.11)	3.27 (5.7)	.013	.17	3.12 (6.8)	.029	.17
	WAB-AQ	78.60 (16.53)	4.05 (5.98)	.002	.24	3.54 (5.76)	.000	.21

Note. ES = effect size; SAPA = Standardized Assessment of Phonology in Aphasia; FOQ = Functional Outcome Questionnaire; SAQOL = Standardized Assessment of Quality of Life; BNT = Boston Naming Test; WAB-AQ = Western Aphasia Battery Aphasia Quotient.

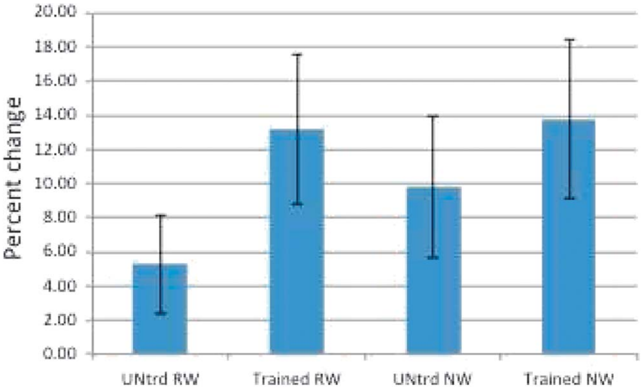
[a]Criteria for judgment of effect size magnitude are those of Cohen (1998): 0.2 = small; 0.5 = medium; and 0.8 = large. [b]Primary outcome measure.

Table 4. Individual pretreatment, immediately posttreatment, and 3-month maintenance results for acquisition (trained items) and generalization (untrained) measures.

	Acquisition measures						Generalization measures								
	Trained nonword repetition			Trained RW naming			SAPA			Untrained nonword repetition			Untrained RW naming		
Participant	Pre	Post	3 months	Pre	Post	3 months	Pre	Post	3 months	Pre	Post	3 months	Pre	Post	3 months[a]
1	59.26	85.65	79.63	84.9	96.83	96	96	106	119	63.93	76.71	80.82	79.7	84.55	81.3
2	93.98	99.54	96.76	89.7	97.62	97.6	128	139	141	92.24	99.54	99.54	91.1	93.5	95.1
3	97.22	98.61	99.54	88.9	96.83	93.7	131	137	135	96.8	100	100	85.4	93.5	87.8
4	80.56	96.3	96.76	68.3	84.13	75.4	74	91	80	87.21	94.52	94.98	67.5	80.49	69.9
5	41.67	68.98	56.94	84.9	90.48	92.1	94	106	105	28.77	47.95	37.9	85.4	74.8	85.4
6	61.11	81.94	76.85	32.5	57.94	54.8	64	74	68	58.9	69.86	71.69	37.4	47.15	39
7	27.31	82.41	75.46	5.6	38.1	15.9	53	59	61	22.83	74.43	65.75	6.5	12.2	4.9
8	45.37	73.15	61.81	32.5	78.57	42.9	80	89	101	35.16	57.08	47.26	29.3	43.09	31.7
9	72.69	80.09	74.54	27	54.76	35.7	61	84	70	75.8	81.74	76.71	35	38.24	36.6
10	95.83	98.61	99.31	86.5	100	100	123	134	131	98.63	98.63	99.32	87.8	93.5	91.5
11	85.19	96.76	97.22	93.7	98.41	100	115	126	136	94.06	94.06	94.98	91.1	91.06	92.7
12	85.42	91.67	92.36	85.7	95.41	94	105	117	113	84.93	94.52	95.21	82.9	87.8	90.2
13	25.93	57.87	60.65	43.7	94.4	92.8	50	94	83	30.59	43.84	52.97	42.3	73.98	75.4
14	57.87	91.2	83.33	42.06	73	85.71	74	89	73	62.1	68.49	72.15	32.52	37.4	48.78
15	83.8	90.74	91.67	63.49	78.6	76.19	106	116	112	84.93	88.58	90.87	65.04	77.2	79.67
16	68.98	90.28	80.09	47.62	61.1	51.59	81	76	92	64.84	79.91	72.15	47.97	49.6	52.85
17	47.69	90.28	82.87	78.57	99.2	98.24	109	119	115	50.68	84.93	85.84	78.05	91.1	89.43
18	63.89	89.35	88.89	93.65	94.6	96.03	114	118	117	69.41	87.67	90.41	88.62	92.7	98.37
19	78.24	98.15	95.37	61.11	96	83.33	72	85	85	88.58	91.78	87.21	66.67	65	65.04
20	88.43	90.74	90.28	81.75	80.2	84.13	113	112	124	91.32	93.15	93.15	86.99	92.7	90.24
21	97.69	98.61	99.07	50	73	64.29	126	140	127	98.17	97.72	98.63	50.41	52.8	58.54
22	75	84.72	86.81	69.84	84.9	84.52	122	121	121	81.74	86.76	82.62	72.36	71.5	71.54
23	75.93	89.81	88.89	86.51	97.6	100	119	126	126	84.93	95.89	90.41	86.18	97.6	94.31
24	95.37	97.69	95.37	50.79	69.8	55.56	127	122	129	94.52	98.17	97.26	60.98	56.9	65.04
25	68.52	81.02	79.17	69.84	77	72.22	128	122	123	66.21	77.17	83.11	61.79	55.3	56.16
26	87.4	89.81	87.96	76.19	99.2	95.24	102	113	113	85.39	89.04	87.21	84.55	87	89.43

Note. All scores are percent correct except the Standardized Assessment of Phonology in Aphasia (SAPA), which is reported in raw score (out of 151 total points). RW = real word.
[a]Column indicates primary outcome measure testing generalization and maintenance simultaneously.

Figure 3. Group mean absolute percent change scores at 3 months posttreatment with 95% confidence intervals. UNtrd = untrained; RW = real words. Error bars represent confidence intervals.



Primary Outcome Results

The primary outcome measure for this study was confrontation naming of untrained nouns at 3 months posttreatment termination. Group pretreatment naming accuracy was 65.52% (*SD* = 23.50) and 3 months posttreatment termination was 70.80% (*SD* = 23.88), indicating a 5.28% absolute increase in performance (*p* = .002) with an ES of 0.22.

Secondary Outcome Results

Acquisition

Trained nonword repetition pretreatment naming accuracy was 71.55% (*SD* = 20.91). Immediately posttreatment, accuracy was 88.23% (*SD* = 10.10), indicating a 16.67% (*SD* = 14.03) absolute increase (*p* = .000).

Confrontation naming of trained nouns pretreatment was 65.20% (*SD* = 24.02). Immediately posttreatment, accuracy was 83.37% (*SD* = 16.59), indicating an 18.16% absolute increase (*p* = .000).

Generalization

Phonologic processing. SAPA pretreatment accuracy was 98.7/151 (*SD* = 25.67). Immediately posttreatment, it was 108.3/151 (*SD* = 21.92), indicating a 9.53% (*SD* = 9.91) absolute increase (*p* = .000).

Untrained nonword repetition pretreatment accuracy was 72.80% (*SD* = 23.07). Immediately posttreatment, it was 83.54% (*SD* = 15.57), indicating a 10.74% (*SD* = 11.49) absolute increase (*p* = .000).

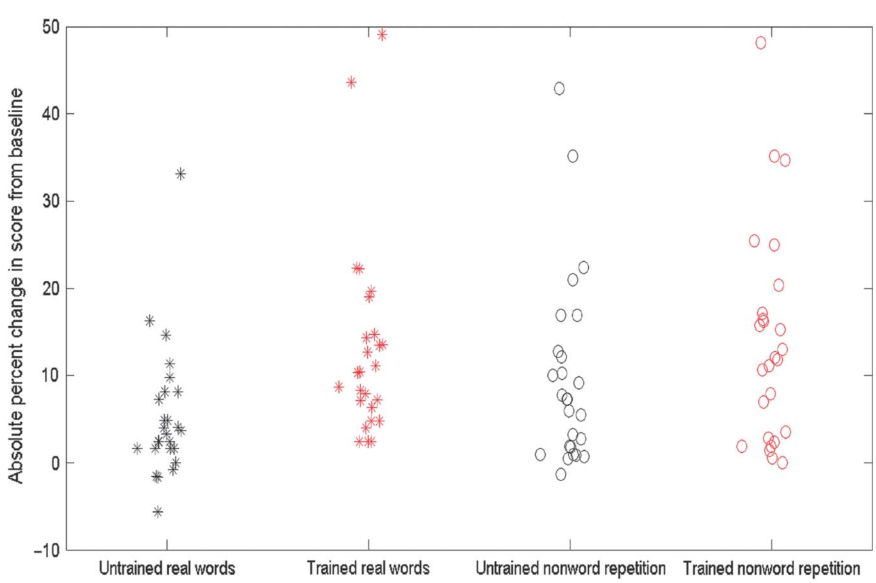
Lexical semantic processing. Untrained real word confrontation naming accuracy pretreatment was 65.52% (*SD* = 23.50). Immediately posttreatment, it was 70.79% (*SD* = 22.91), indicating a 5.27% (*SD* = 8.09) absolute increase (*p* = .003).

Ecologic validity. FOQ pretreatment performance for 25/26 individuals was 4.08 (*SD* = 0.606). Immediately posttreatment (24/26 individuals), it was 4.31 (*SD* = 0.477), indicating an absolute increase of 0.23 (*SD* = 0.47; *p* = .23). SAQOL pretreatment performance was 3.34 (*SD* = 0.71). Immediately posttreatment, it was 3.67 (*SD* = 0.871), indicating an absolute increase of 0.33 (*SD* = 0.68; *p* = .021).

Maintenance

Trained nonword repetition ability at 3 months posttreatment was 85.29% (*SD* = 12.16), indicating a 13.74% absolute increase from pretreatment (*p* = .000). Trained real word confrontation naming at 3 months was 78.38% (*SD* = 22.91), indicating a 13.17% absolute increase from pretreatment (*p* = .000). SAPA score at 3 months was

Figure 4. Scatter plots of individual absolute percentage change scores for confrontation naming of untrained and trained nouns.



107.6/151 (*SD* = 23.62), indicating an 8.96% absolute increase from pretreatment (*p* = .000). Untrained nonword repetition at 3 months was 82.62% (*SD* = 16.67), indicating a 9.83% absolute increase from pretreatment (*p* = .000). FOQ score at 3 months for 21/26 individuals was 4.30 (*SD* = 0.572), indicating an absolute increase of 0.22 from pretreatment (*p* = .069). The SAQOL score 3 months posttreatment performance was 3.68 (*SD* = 0.710), indicating an absolute increase of .34 from pretreatment (*p* = .030).

Standardized Assessment

WAB-AQ pretreatment was 78.6/100 (*SD* = 16.53), immediately posttreatment it was 82.65/100 (*SD* = 12.58; 4.05% absolute change, *p* = .002), and 3 months posttreatment it was 82.14/100 (*SD* = 13.01; 3.54% absolute change, *p* = .000). BNT pretreatment performance was 34.34/60 (*SD* = 18.11), immediately posttreatment it was 37.61/60 (*SD* = 16.17; 3.27% absolute change, *p* = .013), and 3 months posttreatment it was 37.46/60 (*SD* = 17.08; 3.12% absolute change, *p* = .029).

Discussion

The objective of this investigation was to test a further refinement of our phonomotor treatment protocol in a group of 26 PWA who exhibited anomia associated with chronic aphasia due to a single left hemisphere stroke. We sought to determine whether intensively delivered treatment aimed at individual phonemes and phoneme sequences comprising real and nonword stimuli of low phonotactic probabilities and high neighborhood densities would have an advantageous effect on naming abilities. The overarching objective of this study was generalization to words not trained in therapy at 3 months posttreatment termination, thereby testing retention rather than acquisition.

Our results show that confrontation naming of untrained nouns 3 months after completion of treatment was significantly better than before treatment. There was also significant improvement in measures of phonologic generalization and on performance with trained items that was sustained at 3 months, as well as gains on measures of ecologic validity (although the effect sizes for these latter measures fell in the small range).

These results suggest that diminished engagement and processing of phoneme and phonologic sequence knowledge contribute significantly to anomia in participants with aphasia due to stroke and that intensive, multimodal, remediation of phonology does indeed improve word retrieval. However, the heterogeneity of response on the primary outcome measure (see Figure 4) suggests that future implementation of this therapy could be better targeted, provided reliable predictors of response can be identified. It may be that damage to the substrate for semantic processes, or to the links between lexical/semantics and the perisylvian substrate for phonologic knowledge (the neural basis for the phonologic lexicons; Roth et al., 2006), was the predominant contributor to anomia in the nonresponders. A study of predictors of response is in progress.

The present iteration of our treatment incorporates efforts to improve efficiency by utilizing real and nonword training corpuses of items of low phonotactic probability and high phonologic neighborhood density and by reducing treatment hours. The results of the present study suggest that these changes introduced to increase efficiency were successful.

Implications for PDP Theories of Language

The success of this trial, although modest, provides implicit support for the PDP theory that motivated its development (Nadeau, 2001; Roth et al., 2006). The principal source of scientific appeal of the PDP approach is that it is neurally plausible: Symbolic entities and behavioral processes are defined by population-encoded (distributed) representations (as in the brain); the knowledge is in the connections (synapses in the brain); and output is defined by the settling of the activity function of large ensembles of units into quasioptimal states (Nadeau, 2012). As we have seen here, PDP conceptualizations of language function are perfectly compatible with information processing models. PDP models have proven remarkably capable of precisely recapitulating language function in typical participants and participants with brain damage. Most important for our study, it was the PDP-inspired recognition of the substantial orthogonality of semantic and phonologic representations—hence, a substantial absence of regularities encoded in neural connections between substrates for semantics and phonology that might be further developed through treatment—that led us to take a fundamentally different approach to treatment of anomia in aphasia. Finally, this study adds to the growing body of studies that demonstrate that PDP conceptualizations have important implications for aphasia treatment (e.g., Edmonds & Babb, 2011; Kiran & Thompson, 2003; Plaut, 1996; Thompson et al., 2003; see Nadeau, 2012, for further detail).

Comparison With Prior Studies

There is very little basis for direct comparison of this study with prior investigations. In the Wisenburn and Mahoney (2009) meta-analysis, only one of the phonologic therapies assessed generalization beyond completion of therapy, and in that study (Fillingham, Sage, & Lambon Ralph, 2005), participants were tested 1 week after completion of therapy; there was no evidence of generalization. Two studies, involving a total of five participants, both using a verb-centered treatment, reported generalization to unexposed exemplars 3 months after completion of treatment (Bastiaanse, Hurkmans, & Links, 2006; Edwards & Tucker, 2006). The validity of a comparison of the results of a study like ours, involving 26 participants, with small case series, is uncertain. The relative roles of phonologic and semantic therapies, and verb-centered therapy in particular, remain to be determined. The two classes of therapy are not directly comparable, and it is quite possible that many patients with aphasia would benefit from both.

Limitations and Future Directions

The principal limitation of this study is that it was an open trial. The staggered treatment helped to control for any improvement not related to treatment and for the effects of repeated exposure to outcome measures. However, this design feature cannot substitute for a randomized, controlled parallel group design comparing our treatment against an equal dose of customary and usual therapy. Many of our patients might benefit from a combination of phonologic and semantic therapies, and it is possible that many of the participants in this study, most particularly the nonresponders, might have responded to a broadly generalizing semantic therapy, for example, that of Edmonds et al. (2009, 2011). Finally, it is possible that the major contributor to nonresponse was extensive damage to the white matter connectivity between substrates for semantics and phonology—a problem not susceptible to a generalizing treatment, as discussed in the introduction. An analysis of responders and nonresponders is underway. Administration of the large dose of therapy used here would be a challenge in the current health care reimbursement climate. Thus, future trials of treatment using lower dosing are planned. Improving lexical access on naming batteries is not the same as improving lexical access in conversation. To address this issue, discourse data have been collected and are being analyzed. While the evidence of retention of gains documented in this study at 3 months posttreatment is gratifying, evidence of longer-term retention is in order. We plan to report the performance of all of our participants at 1-year posttreatment. Finally, it is possible that long-term retention of gains would have been greater had treatment been distributed over a greater period of time (e.g., 3 hr/week over 20 weeks). Studies conducted over the past 125 years have repeatedly demonstrated, with few exceptions, that long-term retention is enhanced with more distributed treatment—the so-called spacing effect (Nadeau, Gonzalez-Rothi, & Rosenbek, 2008). This study will be conducted in future iterations of this program.

Our study made use of brain imaging (computed tomographs, magnetic resonance images) obtained in the course of clinical care to confirm the presence of lesions and their location in the general vicinity of the dominant Sylvian fissure. Thus, these lesions consistently damaged the perisylvian substrate for phonologic sequence knowledge; connections to it from substrates for semantics, which support lexical representations; and, to varying degree, association cortices encoding semantic knowledge. We did not quantitatively assess the extent of lesions. Methods for achieving such quantitative assessments suffer from serious and unresolved methodologic limitations, most particularly those deriving from the fact that representations are population encoded (Georgopoulos, Kalaska, Caminiti, & Massey, 1982) and, therefore, geographically distributed. It is not clear how lesion analysis would have informed this study.

Conclusion

The results of this open trial of intensive phonologic therapy in 26 participants with chronic poststroke aphasia with anomia provide evidence of generalization of training effects to untrained words and nonwords that was sustained at 3 months and may be clinically significant, at least in treatment responders. These results provide support for the PDP-derived theory that motivated the treatment.

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Phonomotor Treatment Protocol

Treatment materials

- Small mirror
- Line drawings of mouth postures, icons for voiced/voiceless consonants
- Letter tiles
- Wipe-off board with markers
- Small colored blocks

	Stage 1: Sounds in isolation	**Stage 2: Sounds in syllables**
Overview	The purpose of Stage 1 is to train sounds in *isolation* through multimodal 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 speech-language pathologist (SLP) producing a single sound (e.g., /*p*/). SLP asks participant what he or she 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 his or her hand on his or her throat in order to feel for vocal fold vibration (“quiet” vs. “noisy”). Following production, the SLP asks the participant what he or she 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?”). 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?”) to help identify the initial sound /*p*/. Put differently, rather than give the participant a model and tell him or her what the initial sound is, the SLP assists the participant in self-awareness of errors and how to repair them.

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Phonomotor Treatment Protocol

Perception tasks	Perception of sounds in isolation can be trained through various multimodal 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*, he or she would select the pictures corresponding to *p, ee,* and *f*. • **Colored blocks:** If the participant heard the CVCV *peefee*, he or she 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*, he or she 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 is meant to provide an overview and quick reference for those already familiar with the phonomotor treatment program. Readers interested in implementing this program are strongly encouraged to contact the first author of this article for further information.