Top Lang Disorders
Vol. 36, No. 2, pp. 109–122

The Phonomotor Approach to Treating Phonological-Based Language Deficits in People With Aphasia

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The phonomotor treatment program for treating word-retrieval deficits among people with aphasia is inspired by a parallel distributed processing model of lexical processing and is focused at the level of individual phonemes and phoneme sequences. Because verbal production of words involves the translation of a lexical-semantic representation into phonological representations, training the repertoire of phonological sequences should enable individuals with anomia to regain the ability to learn words and sequences, generalize to linguistic items not trained, and continue growth following treatment termination. The development and refinement of the phonomotor treatment program, which began in 2000, have followed the 5-phase model for communication disorders and sciences framework outlined by R. Robey (2004). To date, there have been 8 published articles on the phonomotor treatment program. A large-scale randomized trial comparing phonomotor with standard of care for word-retrieval deficits is underway. The goal of this article is to review the theoretical framework, treatment procedures, current evidence, and future directions of the phonomotor protocol. **Key words:** *anomia*, *aphasia*, *phonomotor*, *rehabilitation*, *treatment*

THEORETICAL BACKGROUND

Phonology is a subfield of linguistics concerned with patterning of sounds in language and is a medium by which sound information is mapped onto higher levels of language such as words. There are theoretical notions supporting phonology in normal language (Blumstein, 1998; Nadeau, 2001). Impaired phonological processes in adult aphasia have been linked to problems in reading (Adair et al., 2000; Conway et al., 1998; de Partz, 1986; Kendall, Conway, Rosenbek, & Gonzalez-Rothi, 2003; Kendall, McNeil, & Small, 1998), language comprehension (Blumstein, 1998; Heilman, Alexander, & Voeller, 1996; Milberg, Blumstein, & Dworetzky, 1988), working memory

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The authors acknowledge the participants and their families who have contributed to this line of research for their time and efforts over the years. The first author is funded by VA RR&D Merit Review Grant C6572R. The contents of this publication do not represent the views of the U.S. Department of Veterans Affairs or the United States government.

The authors have indicated that they have no financial and no nonfinancial relationships to disclose.

Supplemental digital content is available for this article. Direct URL citation appears in the printed text and is provided in the HTML and PDF versions of this article on the journal's Web site (www.topicsinlanguagedisorders.com).

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DOI: 10.1097/TLD.0000000000000085

(Baddeley & Hitch, 1974; Friedman, 2000), and speech production (Browman & Goldstein, 1992; Nadeau, 2001). One particular consequence of phonological disturbance in aphasia results in anomia, a particular common and disabling problem of word production. Anomia may be caused by ischemic damage to the neurological substrate for meaning (semantics); damage to the substrate for phonemic and phonological sequence knowledge; or damage to connections between semantic and phonological substrates, resulting in loss of lexical-semantic knowledge.

Typically, anomia is remediated using real words (nouns or verbs) and tasks such as confrontation naming, repetition, orthographic and phonological cueing, semantic feature analysis, and picture matching using auditory or written words. Although these traditional aphasia therapies have been shown to improve naming performance, generalization can be limited (Wisenburn & Mahoney, 2009). Knowledge gained by the patient may be limited to the words actually trained, with only 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 of individuals with chronic aphasia (Wisenburn & Mahoney, 2009). In their analysis, treatment effects were seen for trained and exposed words (effect size = 2.66), with much less improvement for untrained words (effect size = 0.044). The effect size for trained words declined only modestly over 3 months of follow-up, but the effect size for *untrained* words fell sharply, leading to a global 3-month effect size of 0.48. No treatment (semantic, phonological, or mixed) emerged as superior.

The overarching goal of anomia therapy is to improve production of words that are 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 doomed to be modest unless the scope of intrinsic generalization can be expanded, thereby impacting a significant portion of the semantic domain used in daily life. Broad intrinsic generalization is a challenge for lexical therapies because their principal aim is to reestablish connections between semantic and phonological substrates for single items, one item at a time. 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 production of names of untrained animals; however, it is difficult to develop semantic knowledge that spans the breadth of daily life one semantic category 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.

An alternative approach (called phonomotor therapy) to remediating anomia that has shown promise focuses on training a corpus of phonemes in isolation and phonemes in English-permissible sequences. Because verbal production of words involves the translation of a lexical-semantic representation into phonological representations, training the repertoire of phonological sequences should enable individuals with anomia to regain the ability to learn trained words and sequences, generalize to untrained items, and continue growth following treatment termination. Furthermore, because all words in a language make use of the same phonological sequence repertoire, phonological therapy has the potential for broad generalization. We have been developing and systematically testing a phonological sequence-based therapy, called phonomotor treatment (Kendall et al., 2003; Kendall, Nadeau, et al., 2006; Kendall, Rodriquez, Rosenbek, Conway, & Gonzalez-Rothi, 2006; Kendall et al., 2008; Raymer, Haley, & Kendall, 2002).

The application of phonomotor therapy is predicated on there being a loss of phoneme and phonological sequence knowledge as a result of dominant perisylvian brain damage due to stroke. Classically, this is manifested as phonemic paraphasic errors in naming to confrontation, spontaneous language, and reading aloud. However, such paraphasic errors are manifest only if the erroneous phonological representations that are generated reach the threshold for verbal production. If they do not reach this threshold, they may manifest as anomia (Nadeau, 2001). This hidden deficit in phonological sequence knowledge is highly prevalent and has been revealed in the use of a phonological measure we developed—the Standardized Assessment of Phonology in Aphasia (SAPA, see later description; Kendall et al., 2010).

The phonomotor treatment is inspired by a parallel distributed processing (PDP) model of lexical processing (Nadeau, 2001; Roth, Nadeau, Hollingsworth, Cimino-Knight, & Heilman, 2006; Figure 1) and the Lindamood Phoneme Sequencing therapy program (Lindamood & Lindamood, 1998; see Kendall et al., 2008, for extensive overview of the theoretical underpinnings). In this PDP-model-driven approach to treatment of phonological 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 phonological 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 phonological sequence knowledge (Nadeau, 2001).

The hypothesis motivating the phonomotor treatment approach has been discussed elsewhere extensively (see Kendall et al., 2008; Kendall, Oelke, Brookshire, & Nadeau, 2015). It is briefly reiterated here. Through intensive, neurally distributed, multimodal (auditory, motor, orthographic, tactile-kinesthetic, and conceptual) training of phonemes and one-, two-, and three-syllable real-word and nonword phoneme sequences, the neural connectivity supporting phoneme sequence knowledge is proposed to be enhanced. Because knowledge of phonemes and phoneme sequences provides the basis for the production of all words, naming of untrained words and discourse production may be improved with rehabilitation. The hypotheses are predicated upon the existence, in damaged form, of exactly the same networks that enabled these patients to acquire language in the first place. When phonomotor treatment is intensively delivered (2 hr/day, 5 days/week for 6 weeks), confrontation naming performance improves on trained real words and nonword repetition. In addition, we have shown that there is generalization to picture naming using 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 et al., 2002).

The differences between our treatment and other semantic-phonological treatments involve both the nature of the stimuli and degree of intensity. Other semantic phonological treatments potentially strengthen phonological sequence knowledge predominantly through induction of Hebbian learning (Hebb, 1949) using real words. Our treatment employs training of individual phonemes and phoneme sequences mostly embedded in nonwords, with limited exposure to real words. Phonomotor treatment also is unprecedented in its systematicity and its dose. Furthermore, unlike other phonological treatments, the phonomotor treatment is based on the notion of distributed (auditory, articulatory, orthographic, visual) phonological representations, which, when refined through multimodal training, improve phonological awareness. Hebbian learning is achieved through introduction of real words into the training algorithm, therefore, serves only as an adjuvant to our core training procedures.

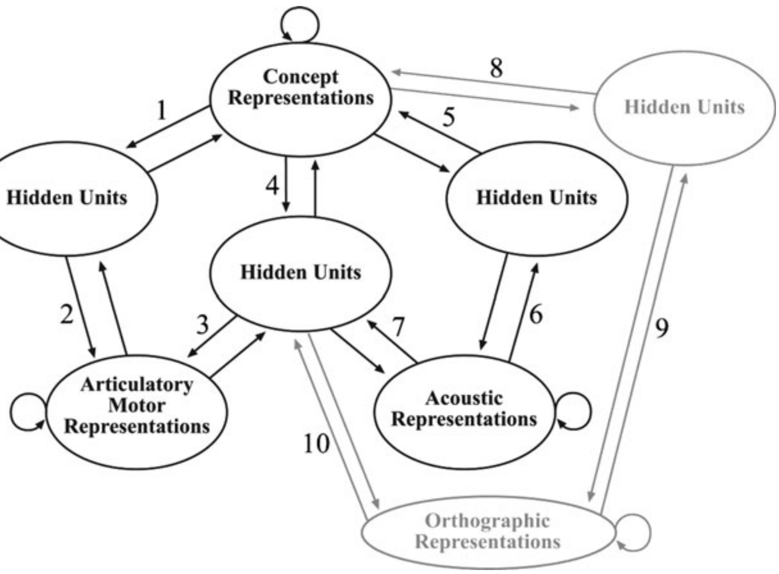

Figure 1. Proposed parallel distributed processing model of language. Each oval should be interpreted as a large number of units, each unit connected to every unit in each connected oval (represented by numbers). Knowledge is represented as the strength of connections between units. Hidden units enable the establishment of a functional linkage between forms that have an arbitrary relationship to each other (e.g., word meaning and word phonology). Connectivity within the substrate for concept representations defines semantic knowledge. Connectivity within the perisylvian acoustic-articulatory motor pattern associator network defines phonological sequence knowledge. Connectivity between the substrate for concept representations and the acoustic-articulatory motor pattern associator defines lexical knowledge (the phonological 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 phonological 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 phonological (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 phonological sequence knowledge. From "Phonology: A Review and Proposals From a Connectionist Perspective," by S. E. Nadeau, 2001, *Brain and Language, 79*, pp. 511–579. Copyright 2001 by Elsevier Science (USA). Reproduced with permission.

EVALUATION OF PHONOLOGICAL DEFICITS IN APHASIA

The SAPA (Kendall et al., 2010) is an impairment-level test of phonology for individuals with a wide range of aphasia severities and types. The SAPA can be used as a tool to distinguish phonological– versus semantic–based deficits, as a guide for clinical treatment, and as an outcome measure for neurorehabilitation protocols. It consists of three subtests—reading aloud, repetition/parsing/blending, and auditory phonological perception (rhyming/lexical decision making). Item Response Theory (IRT) analysis was used to guide test construction. First, a model of phonology was identified (Nadeau, 2001) and three constructs within the model were delineated (reading, repetition/parsing/blending, perception). Items were developed for each construct using psycholinguistic principles thought to be relevant to performance. Second, items were reviewed by experts in the field and were revised accordingly. Then, the SAPA was field tested with 47 individuals with chronic aphasia and IRT statistics were generated. Performance from individuals with aphasia on the SAPA showed reasonable fit to the Rasch measurement model, with less than 2% of the items misfitting and good point measure correlations. The hypothesized hierarchical structure for each of the three constructs matched the actual hierarchy with one exception (parsing/blending). The item hierarchies were successful in differentiating patterns of phonological dysfunction in individuals with aphasia. Thus, the three tests that comprise the SAPA can be utilized to detect impairment-level deficits in behaviors strongly linked to phonology (reading, repetition, parsing/blending, and perception) in individuals with aphasia. We have used the SAPA as a sensitive and specific measure of change in phonological mechanisms in many of our studies evaluating the phonomotor treatment approach, as described later.

PHONOMOTOR TREATMENT PROCEDURES

Treatment guidelines have been outlined in Kendall et al.'s (2015) study and are also included here (see Supplement Digital Content Appendix, available at: http://links.lww.com/TLD/A52). Essentially, phonomotor treatment is an explicit, multimodal (orthographic, auditory, articulatory-motor, tactile-kinesthetic, visual, and conceptual), phonological based treatment using phonemes in isolation and one-, three-, and three-syllable phoneme sequences in real-word and nonword combinations. Treatment is delivered across two stages: Stage 1 treats sounds in isolation, and Stage 2 treats sound combinations (e.g., CV, VC, CVC, CCVC). Socratic questioning (i.e., disciplined questioning) is a key element in feedback.

Treatment stimuli

The stimuli that have been developed for the treatment program are a crucial part of the intervention. The stimuli are composed of phonemes in isolation and one-, two-, and three-syllable phoneme sequences in real-word and nonword combinations consisting of phonological sequences of low phonotactic probability and high neighborhood density. This approach is based on the work by Storkel, Armbruster, and Hogan (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 phonotactic probability) triggered learning more efficiently than more common sound sequences (high phonotactic probability) consistent with the results of Plaut (1996), Kiran and Thompson (2003), and Thompson, Shapiro, Kiran, and Sobecks (2003). Employment of high neighborhood density maximized the number of potential semantic representations engaged bottom-up by any given phonological sequence, thereby maximizing the opportunity for strengthening semantic-phonological connectivity (lexical-semantic knowledge) in daily conversation. The stimuli have been listed in Kendall et al.'s (2015) study and are also included in Table 1. On the basis of theoretically understanding and current evidence available, the use of these stimuli is recommended when delivering this treatment program.

Eighty-three real words (42 trained and 41 untrained) and 145 nonwords (72 trained and 73 untrained) are used in the phonomotor treatment program. Phonotactic probability was calculated using methods similar to those of Vitevitch and Luce (1999). All nonwords are phonotactically legal in English. A Web-based interface was used to calculate phonotactic probabilities for the real words and nonwords (Vitevitch & Luce, 2004). Neighborhood density was computed by counting the number of words in the dictionary that differed from the target by a one phoneme addition, deletion, or substitution.

Table 1. Trained and untrained stimuli used in treatment

		Real Words				Nonwords			
Trained Sounds in Isolation		Trained		Untrained		Trained (Graphemes) (IPA)		Untrained (Graphemes) (IPA)	
IPA Symbol	Graphemes	One Syllable	Two Syllable	One Syllable	Two Syllable	One Syllable	Two Syllable	One Syllable	Two Syllable
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 (ɑɪdʒ)	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								

Note. IPA = International Phonetic Alphabet. From "The Influence of Phonomotor Treatment on Word Retrieval Abilities in 26 Individuals With Chronic Aphasia: An Open Trial," by D. L. Kendall, M. Oelke, C. E. Brookshire, and S. Nadeau, 2015, *Journal of Speech, Language, and Hearing Research*, *58*(3), pp. 798–812. doi:10.1044/2015_JSLHR-L-14-0131. Copyright 2015 by the American Speech-Language-Hearing Association. Reprinted with permission..

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.

CURRENT EVIDENCE

The development and refinement of the phonomotor treatment program have followed the five-phase model for communication disorders and sciences framework outlined by Robey (2004). To date, there have been eight published articles on the phonomotor treatment program (see Table 2). The purpose of Phase I research is to identify

Table 2. References for phonomotor treatment development

Reference	Phase	Design	Number of Participants	Intensity and Frequency	Focus of Study	Outcomes
Raymer et al., 2002	I	Single subject	$n = 1$	1 hr/day, 4 days/week for 20 total hr	Apraxia of speech	Improved imitation for two trained sounds, generalization to untrained voiceless cognates. No improvement for 1 trained sound and overgeneralization evident.
Kendall, Nadeau, et al., 2006	I	Single subject	$n = 1$	1–2 hr/day, 3–4 days/ week over 6 months (total 74 hr)	Alexia	Improved silent reading comprehension and generalized language function (WAB). Lack of improvement in real-word reading aloud (likely due to apraxia of speech).
Kendall et al., 2003	I	Single subject	$n = 2$	Subject 1: 3 hr/day, 4 days/week over 5 months (total 162.5 hr) Subject 2: 2 hr/day, 4 days/week over 4 months (total 78 hr)	Alexia	Improved real-word reading aloud, word comprehension, and generalized language function (WAB).
Kendall, Rodriguez, et al., 2006	I	Single subject	$n = 1$	2 hr/day, 4–5 days/week over 3.5 months (total 104 hr)	Apraxia of speech	Improvement in individual sound production, less effortful discourse production, and self-report less apprehensive when speaking. No improvement in repetition of multisyllabic words.

(*continues*)

Table 2. References for phonomotor treatment development (*Continued*)

Reference	Phase	Design	Number of Participants	Intensity and Frequency	Focus of Study	Outcomes
Bislick et al., 2014	I	Single subject	$n = 1$	2 hr/day, 4 days/week over 6 weeks (total 48 hr)	Apraxia of speech	Improvement in trained sounds, generalization to untrained sounds, real words and nonwords composed of trained sounds and a measure of ecological validity.
Kendall et al., 2008	II	Single subject	$n = 10$	2 hr/day, 5 days/week for 12 weeks (96 total hours)	Lexical retrieval	Improvement in confrontation naming of untrained exemplars 3 months posttreatment termination.
Brookshire et al., 2014	II	Retrospective, single group	$n = 8$	2 hr/day, 5 days/week, 6 weeks (60 total hours)	Alexia	Improvement in phonological processing and oral reading of real words and nonwords 3 months posttreatment termination. No improvement on reading comprehension (likely due to task requirements and confounds with anomia).
Kendall et al., 2015	II	Staggered (immediate vs. delayed treatment) open-trial design	$n = 26$	2 hr/day, 5 days/week, 6 weeks (60 total hours)	Lexical retrieval	Improvement in confrontation naming of untrained exemplars 3 months posttreatment termination.

Note. WAB = Western Aphasia Battery.

a therapeutic effect and, if an effect is present, to capture estimates of effect size. During Phase I work, the dose of treatment needs to be estimated, as do the appropriate patient populations. There have been five Phase I trials of phonomotor treatment (Bislick, Oelke, & Kendall, 2014; Kendall, Nadeau, et al., 2006; Kendall, Rodriguez, et al., 2006; Kendall et al., 2003; Raymer et al., 2002). All of the Phase I studies employed single-subject designs involving individuals with aphasia from a left-hemisphere stroke with the goal of improving phonological alexia (Kendall et al., 2003; Kendall, Nadeau, et al., 2006) and apraxia of speech (Bislick et al., 2014; Kendall, Rodriguez, et al., 2006; Raymer et al., 2002). The results of these studies are summarized in Table 2 and are discussed in more detail later.

Phase I evidence

Individuals for whom phonomotor treatment has been tested include those with chronic aphasia (6 or more months after left-hemisphere damage due to a single left cerebral hemisphere stroke) with anomia and impairment of phonology. Presence of aphasia has been 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 phonological impairment have been 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). With the exception of Bislick et al.'s (2014) and Raymer et al.'s (2002) studies, participants have been excluded if they exhibited severe apraxia of speech defined by a slowed speaking rate (prolonged sounds and/or intersegment durations), distortions and/or distorted substitutions, and prosodic abnormalities during discourse production, repetition of words and nonwords, and naming tasks. Additional exclusion criteria across these trials have included major depressive disorder or other psychiatric illness, degenerative neurological disease, chronic medical illness, or severe and/or uncorrected impairment in vision or hearing.

With regard to alexia, Kendall et al. (2003) showed a positive effect following phonomotor treatment manifest as improved real-word reading aloud of untrained words as well as improvement in posttest measures of real-word comprehension. Effects of treatment and generalization were maintained 3 months following treatment termination. As in the 2003 study, Kendall, Nadeau, et al. (2006) administered phonomotor treatment to a single individual, who 54 years prior to the start of the study survived a left-hemisphere cerebrovascular accident (CVA), resulting in aphasia, apraxia of speech, and alexia. The results showed improvement in silent reading comprehension (Reading Comprehension Battery for Aphasia; LaPointe& Horner, 1979), lack of improvement in real-word reading aloud (likely due to mild-moderate apraxia of speech), and an unexpected improvement in language function (WAB-AQ, Kertesz, 1982; BNT, Kaplan et al., 1983). The results of these two studies, taken together, showed that by applying an intensive, multimodal treatment to the level of the phoneme and phoneme sequences, reading, spoken word production (Kendall, Nadeau, et al., 2006), and word comprehension (Kendall et al., 2003) improved in individuals with aphasia.

Finally, in keeping with Phase I objectives, we were interested in learning whether phonomotor treatment would improve phoneme production and generalize to untrained words in individuals with apraxia of speech. Raymer et al. (2002) treated several sounds in a single individual for 20 total hours (1 hr/day, 4 days/week) and showed improved imitation for two trained sounds, generalization to untrained voiceless cognates. However, there was no improvement for one trained sound and some overgeneralization was evident. Kendall, Rodriguez, et al. (2006) provided phonomotor treatment to a single individual with apraxia of speech for 104 hr (over the course of 3.5 months). Although he was able to learn individual sounds following treatment, he did not exhibit generalization to other aspects of motor production (e.g., repetition of multisyllabic words). That said, discourse production was perceptually judged to be slower and less effortful, and the participant reported increased phone usage and ease of communication. Bislick et al. (2014) provided phonomotor treatment to an individual with severe apraxia of speech for a total of 48 hr (2 hr/day, 4 days/week). Results from that trial showed improvement in trained sounds, generalization to untrained sounds, real word and nonwords composed of trained sounds, and a measure of ecological validity. We were confident that the evidence from the aforementioned studies was sufficient to move to the next phase of clinical research: Phase II.

Phase II evidence

According to Robey (2004), Phase II research studies should determine effect size intervals, refine the population, refine the treatment protocol, develop a treatment administration manual, determine optimal dosage, identify valid and reliable measurement instruments, and finalize operational definitions. To this end, we conducted two Phase II studies (Kendall et al., 2008, 2015) and developed the SAPA, a standardized outcome measure that can be used in future clinical trials, as described previously (Kendall et al., 2010). The final Phase II study, a randomized controlled trial (multisite), is currently underway comparing phonomotor with customary and usual therapy (semantic feature analysis) in a group of 80 persons with aphasia, with the primary outcome measure of confrontation naming of pictures of untrained items at 3 months posttreatment termination (thus testing generalization and maintenance simultaneously).

The first Phase II study was promising (Kendall et al., 2008). This study extended the initial Phase I findings by (1) comparing the experimental phonological treatment with a semantic treatment, (2) refining the experimental treatment in terms of using a homogeneous patient population, and (3) increasing the frequency and intensity of treatment. Twenty individuals with anomia due to aphasia were randomized to receive either 96 hr of phonomotor or semantic treatment delivered in a massed practice condition over 12 weeks with 3-month follow-up. Results on impairment-level outcome measures showed that treatment and generalization effects in the phonomotor treatment group were superior to those of the semantic group. Measures of ecological validity (ASHA-FACS) showed that the phonomotor intervention had a meaningful impact on communication at home (7.35 average difference score at 3 months posttreatment termination). With concerns regarding the large dosage of treatment hours delivered, a post hoc analysis revealed that treatment effects for both groups were acquired by 60 hr of treatment and there was no significant change in effect sizes within group between 60 and 96 hr of treatment delivered.

Results from Kendall et al.'s (2008) study provided sufficient evidence to move to the next Phase II study; however, refinements in the treatment protocol were warranted. In Kendall et al.'s (2008) study, both groups received a number of treatment hours that seemed excessive, given the medical reimbursement climate and the evidence from the outcome data that gain plateaued after about 60 hr (see the earlier discussion). Second, there were potential opportunities for improving the efficiency of the phonomotor therapy, specifically, by limiting the training material to phonemes and phoneme sequences of low phonotactic probability and large phonological neighborhoods. Third, a sensitive and specific measure of phonology for adults with aphasia had not been employed, limiting our ability to ensure that phonological mechanisms were indeed directly impacted by the treatment. To that end, the SAPA (Kendall et al., 2010) was created. All three of these innovations were instantiated in Kendall et al.'s (2015) study.

Kendall et al. (2015) employed a staggered (immediate vs delayed treatment) open-trial group design in which 26 individuals with aphasia received 60 total hours of treatment (2 hr/day, 5 days/week). The primary outcome measure was generalization to untrained stimuli at 3 months (testing generalizing and maintenance). The results showed an absolute increase of 5% in confrontation naming of pictures representing untrained nouns at 3 months and improvements on measures of phonological processes. Furthermore, Brookshire, Conway, Hunting Pompon, Oelke, and Kendall (2014) conducted a retrospective analysis of reading abilities in eight individuals from Kendall et al.'s (2015) study, who exhibited phonological alexia. Results showed improvement in oral reading of real words and nonwords 3 months posttreatment termination. Although no improvement in reading comprehension was found, it was likely due to task requirements (i.e., spoken word production). In other words, the task required the participants to read a sentence and respond verbally requiring word-retrieval mechanisms in addition to comprehension of the written sentence.

Although phonomotor treatment has been tested at varying dosages, the data from the largest trial (Kendall et al., 2015) suggest that treatment intensity should be 2 hr/day, 5 days/week for 6 weeks (60-hr total practice). Because the current dosage is incompatible with current delivery models, future research is planned to test effects of massed versus distributed practice.

CONCLUSIONS AND FUTURE DIRECTIONS

The phonomotor treatment approach to rehabilitating anomia in aphasia has shown promise. Although the results of the largest ($n = 26$) study (Kendall et al., 2015) were promising, several limitations were noted. The efficacy of phonomotor therapy needs to be compared against standard care treatment (e.g., a lexical-semantic based treatment), and that trial is currently underway. The current iteration of the phonomotor treatment now includes modified stimuli (real words and nonwords with low phonotactic probability and high neighborhood density), reduction of the total number of treatment hours (from 96 to 60 total hours), and refinement of the primary and secondary outcome measures (addition of the SAPA, as well as new measures of discourse production and ecological validity).

Limitations of phonomotor treatment continue to include the large, massed practiced dose. Administration of phonomotor treatment, as has been tested, would be a challenge in the current health care reimbursement climate. Thus, future trials of treatment employing lower dosing are planned. Although the evidence of retention of gains documented in these studies at 3 months posttreatment is gratifying, evidence of longer term retention is in order. We plan to report the performance of the patients from Kendall et al.'s (2015) study at 1 year posttreatment. 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.

Finally, as we have shown, phonomotor therapy was efficacious in only approximately 50% of our participants. Thus, predictors of response studies are needed to enable better targeting of this time-consuming treatment. Finally, phonomotor therapy appears to be most appropriate for participants who have evidence of some remaining substrate for phonology. We administered phonomotor treatment, coupled with an intensive, home-based, semantic treatment, to a single individual who, 54 years prior to the start of treatment, suffered a left-hemisphere CVA, resulting in aphasia, apraxia of speech, and alexia (Kendall, Nadeau, et al., 2006). The participant demonstrated substantial improvement in language function, as measured by the WAB-AQ (Kertesz, 1982), and performance on the BNT (Kaplan et al., 1983), but no improvement in phonological function.

We have reported proof-of-concept studies that suggest that phonomotor therapy may be of value in patients with mild-moderate apraxia of speech and in patients with reading impairment after stroke. In nearly all patients with alexia after stroke, the alexia is either phonological or deep (Brookshire et al., 2014). One would therefore expect enhancement of phonological sequence knowledge to be beneficial for some patients with poststroke alexia.

In most patients with aphasia after stroke, deficits in a number of components of brain function contribute to the aphasia. Thus, in patients with a middle cerebral distribution infarction, one could build a strong case for a multiphase treatment addressing multiple levels of linguistic processing, for example, beginning with phonomotor treatment to enhance phonological sequence knowledge, followed by a semantic therapy (e.g., vNEST; Edmonds, 2016; Edmonds et al., 2009) to ameliorate the semantic deficit, and culminating in constraint-induced language therapy to redress the loss of intentional predisposition to use oral language to communicate. Also, the use of alternative augmentative communication or other compensatory approaches, coupled with patient/family education, is appropriate in some cases.

Neuroplastic effects achieved with such functionally specific behavioral therapies might benefit from adjuvants to learning or neuroplasticity, both pharmacological (e.g., donepezil, an acetylcholinesterase inhibitor; Nadeau et al., 2004) and electrophysiological (e.g., repetitive transcranial magnetic stimulation and transcranial direct current stimulation). It is possible that the speech–language therapy environment might be tuned to minimize factors such as anxiety that might interfere with learning (D. K. Pompon, personal communication, December 1, 2015), or to enhance retention. This could be done, for example, by conducting treatment in the patient's home, thereby maximizing the similarities in context at time of learning and time of retrieval—one of the posited mechanisms of the spacing effect.

In the longer run, the "fill up your tank with rehabilitation" model is likely to become an anachronism as therapies evolve that can be continued indefinitely by the patient and his/her family, perhaps with intermittent guidance by the speech–language pathologist. In this respect, deficit-specific therapies will need to meld with life participation approaches (Elman, 2016).

REFERENCES

Adair, J. C., Nadeau, S. E., Conway, T. W., Rothi, L. G. J., Heilman, P., Green, I. A., et al. (2000). Alterations in the functional anatomy of reading induced by a phonological articulatory rehabilitation strategy in an alexic aphasic patient. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology*, *13*(4), 303–311.

Baddeley, A. D., & Hitch, G. (1974). *Working memory*. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47–89). New York: Academic Press.

Bislick, L. P., Oelke, M., & Kendall, D. (2014). Phonomotor rehabilitation of apraxia of speech. *Journal of Medical Speech-Language Pathology*, *21*(1), 15–31.

Blumstein, S. E. (1998). Phonological aspects of aphasia. In M. Sarno (Ed.), *Acquired aphasia* (pp. 157–185). New York: Academic Press.

Brookshire, C. E., Conway, T., Hunting Pompon, R., Oelke, M., & Kendall, D. (2014). Effects of intensive phonomotor treatment on reading in eight individuals with aphasia and phonological alexia. *American Journal of Speech-Language Pathology*, *23*, S300–S311.

Browman, C. P., & Goldstein, L. (1992). Articulatory phonology: An overview. *Phonetica*, *49*, 155–180.

Coltheart, M. (1981). *MRC Psycholinguistic Database*. UWA Psychology, School of Psychology, University of Western Australia. Retrieved from http://websites.psychology.uwa.edu.au/school/MRCDatabase/mrc2.html

Conway, T. W., Heilman, P., Gonzalez-Rothi, L., Alexander, A. W., Adair, J., Crosson, B., et al. (1998). Treatment of a case of phonological alexia with agraphia using the Auditory Discrimination in Depth (ADD) program. *Journal of the International Neuropsychological Society*, *4*, 608–620.

de Partz, M. P. (1986). Re-education of a deep dyslexia patient: Rationale of the methods and results. *Cognitive Neuropsychology*, *3*(2), 149–177.

Edmonds, L. A. (2016). A review of Verb Network Strengthening Treatment: Theory, methods, results, and clinical implications. *Topics in Language Disorders*, *36*(2), 123–135.

Edmonds, L. A., & Babb, M. (2011). Effect of verb network strengthening treatment in moderate-to-severe aphasia. *American Journal of Speech-Language Pathology*, *20*, 131–145. doi.org/10.1044/1058-0360(2011/10-0036)

Edmonds, L. A., Nadeau, S. E., & Kiran, S. (2009). Effect of verb network strengthening treatment (VNeST) on lexical retrieval of content words in sentences in persons with aphasia. *Aphasiology*, *23*, 402–424. doi.org/10.1080/02687030802291339

Elman, R. J. (2016). Aphasia centers and the life participation approach to aphasia: A paradigm shift. *Topics in Language Disorders*, *36*(2), 154–167.

Friedman, R. (2000). The role of learning and memory paradigms in the remediation of aphasic disorders. *Brain and Language*, *71*, 69–71.

Forde, E. M. E., & Humphreys, G. W. (1999). Category specific recognition impairments: A review of important case studies and influential theories. *Aphasiology*, *13*, 169–193.

Hebb, D. O. (1949). *The organization of behavior*. New York: Wiley.

Heilman, K. M., Alexander, A. W., & Voeller, K. (1996). Developmental dyslexia: A motor-articulatory feedback hypothesis. *Annals of Neurology*, *39*, 407–412.

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

Kendall, D., McNeil, M. R., & Small, S. L. (1998). Rule-based treatment for acquired phonological dyslexia. *Aphasiology*, *12*(7–8), 587–600.

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

Kendall, D. L., del Toro, C., Nadeau, S. E., Johnson, J., Rosenbek, J., & Velozo, C. (2010, June). *The development of a standardized assessment of phonology in aphasia*. Paper presented at the Clinical Aphasiology Conference, Isle of Palm, SC.

Kendall, D. L., Nadeau, S. E., Conway, T., Fuller, R. H., Riestra, A., & Gonzalez-Rothi, L. (2006). Treatability of different components of aphasia: Insights from a case study. *Journal of Rehabilitation Research & Development*, *43*, 323–335. doi:10.1682/Jrrd.2005.01.0014

Kendall, D. L., Oelke, M., Brookshire, C. E., & Nadeau, S. (2015). The influence of phonomotor treatment on word retrieval abilities in 26 individuals with chronic aphasia: An open trial. *Journal of Speech, Language, and Hearing Research*, *58*(3), 798–812. doi:10.1044/2015_JSLHR-L-14-0131

Kendall, D. L., Rodriguez, A. D., Rosenbek, J. C., Conway, T., & Gonzalez-Rothi, L. (2006). Influence of intensive phonomotor rehabilitation on apraxia of speech. *Journal of Rehabilitation Research & Development*, *43*, 409–418. doi:10.1682/Jrrd.2005.11.0175

Kendall, D. L., Rosenbek, J. C., Heilman, K. M., Conway, T., Klenberg, K., Gonzalez-Rothi, L., et al. (2008). Phoneme-based rehabilitation of anomia in aphasia. *Brain and Language*, *105*, 1–17. doi:10.1016/j.bandl.2007.11.007

Kertesz, A. (1982). *Western Aphasia Battery*. New York: Grune & Stratton.

Kiran, S., & Thompson, C. K. (2003). Effect of typicality on online category verification of animate category exemplars in aphasia. *Brain and Language*, *85*, 3441–3450. doi:10.1016/S0093-934X(03)00064-6

LaPointe, L. L., & Horner, J. (1979). *Reading comprehension battery for aphasia*. Austin, TX: PRO-ED.

Lindamood, C. H., & Lindamood, P. C. (1998). *The Lindamood phoneme sequencing program for reading, spelling, and speech*. Austin, TX: PRO-ED.

McNeil, M. R., Doyle, P. J., Spencer, K. A., Goda, A. J., Kendall, D. L., & Small, S. L. (1997). A double-blind, placebo-controlled study of pharmacological and behavioral treatment of lexical-semantic deficits in aphasia. *Aphasiology*, *11*, 385–400. doi:10.1080/02687039708248479

McNeil, M. R., & Pratt, S. R. (2001). Defining aphasia: Some theoretical and clinical implications of operating from a formal definition. *Aphasiology*, *15*(10–11), 901–911. doi.org/10.1080/02687040143000276

Milberg, W., Blumstein, S., & Dworetzky, B. (1988). Phonological processing and lexical access in aphasia. *Brain & Language*, *34*(2), 279–293.

Nadeau, S. E. (2001). Phonology: A review and proposals from a connectionist perspective. *Brain and Language*, *79*, 511–579. doi:10.1006/brln.2001.2566

Nadeau, S. E., Behrman, A. L., Davis, S. E., Reid, K., Wu, S. S., Stidham, B. S., et al. (2004). Donepezil: Possibly effective adjuvant to constraint induced therapy for upper extremity dysfunction after stroke. *Journal of Rehabilitation Research and Development*, *41*, 525–535.

Nadeau, S. E., Gonzalez-Rothi, L., & Rosenbek, J. C. (2008). Language rehabilitation from a neural perspective. In: R. Chapey (Ed.), *Language intervention strategies in aphasia and related neurogenic communication disorders* (5th ed., pp. 689–734). Philadelphia: Lippincott Williams & Wilkins.

Nickels, L. (2002). Therapy for naming disorders: Revisiting, revising and reviewing. *Aphasiology*, *16*, 935–980. doi:10.1080/02687030244000563

Plaut, D. C. (1996). Relearning after damage in connectionist networks: Toward a theory of rehabilitation. *Brain and Language*, *52*, 25–82. doi:10.1006/brln.1996.0004

Raymer, A. M., Haley, M. A., & Kendall, D. L. (2002). Overgeneralization in treatment for severe apraxia of speech: A case study. *Journal of Medical Speech Pathology*, *10*(4), 313–317.

Robey, R. (2004). A five-phase model for clinical-outcome research. *Journal of Communication Disorders*, *37*(5), 401–411. doi.org/10.1016/S0021-9924(04)00039-5

Roth, H. L., Nadeau, S. E., Hollingsworth, A. L., Cimino-Knight, A. M., & Heilman, K. M. (2006). Naming concepts: Evidence of two routes. *Neurocase*, *12*, 61–70. doi:10.1080/13554790500502892

Silkes, J. P., Dierkes, K. A., & Kendall, D. L. (2012). Masked repetition priming effects on naming in aphasia: A Phase I treatment study. *Aphasiology*, *27*, 381–397. doi:10.1080/02687038.2012.745475

Storkel, H. L., Armbruster, J., & Hogan, T. P. (2006). Differentiating phonotactic probability and neighborhood density in adult word learning. *Journal of Speech, Language, and Hearing Research*, *49*, 1175–1192. doi:10.1044/1092-4388(2006/085)

Thompson, C. K, Shapiro, L. P., Kiran, S., & Sobecks, J. (2003). The role of syntactic complexity in treatment of sentence deficits in agrammatic aphasia: The complexity account of treatment efficacy (CATE). *Journal of Speech, Language, and Hearing Research*, *46*, 591–607. doi.org/10.1044/1092-4388 (2003/047)

Vitevitch, M. S., & Luce, P. A. (1999). Probabilistic phonotactics and neighborhood activation in spoken word recognition. *Journal of Memory and Language*, *40*, 374–408. doi:10.1006/jmla.1998.2618

Vitevitch, M. S., & Luce, P. A. (2004). A Web-based interface to calculate phonotactic probability for words and nonwords in English. *Behavior Research Methods Instruments & Computers*, *36*, 481–487. doi:10.3758/BF03195594

Warrington, E. K., & McCarthy, R. (1987). Categories of knowledge. Further fractionation and an attempted integration. *Brain*, *110*, 1273–1296.

Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain*, *107*, 829–854.

Wisenburn, B., & Mahoney, K. (2009). A meta-analysis of word-finding treatments for aphasia. *Aphasiology*, *23*, 1338–1352. doi.org/10.1080/02687030902732745