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An Analysis of Aphasic Naming Errors as an Indicator of Improved Linguistic Processing Following Phonomotor Treatment

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Purpose: The aim of this study was to investigate the influence of phonomotor treatment on the types of errors produced during a confrontation naming task for people with aphasia (PWA).
Method: Ten PWA received 60 hr of phonomotor treatment across 6 weeks. Confrontation naming abilities were measured before and after treatment, and responses were coded as correct or incorrect. Incorrect responses were coded for error type. Paired *t* tests comparing pre-, post- and 3 months posttreatment naming accuracy and error type were performed.
Results: Group data showed that naming accuracy on trained items improved significantly immediately post treatment, and gains were maintained 3 months later. Naming accuracy on untrained items did not show significant improvement immediately post treatment or 3 months later. Results of error type analysis were not significant. However, a decrease in omission errors and an increase in mixed errors were noted immediately post treatment for naming of untrained items.
Conclusion: Results suggest that intensive phonomotor treatment improved lexical-retrieval abilities and may have triggered a shift in linguistic processing, as indicated by a decrease in omission errors on trained items and an increase in mixed errors on untrained items.

Key Words: aphasia, anomia, phonomotor treatment, error analysis

As part of a Phase II clinical rehabilitation research study, we explored the influence of an aphasia treatment on the types of speech errors that are produced by people with aphasia (PWA) during a confrontation naming task. Ten PWA were tested before, immediately after, and 3 months after an intensive phonomotor treatment program. We were interested in knowing if treatment aimed at the level of phonological processes would decrease the overall number of errors made during word production and if the type of errors (e.g., semantic, phonologic, omission, etc.) would change following treatment, thus indicating a shift in the level of linguistic processing.

The intensive phonomotor treatment program employed in this study was developed through a series of Phase I and Phase II trials (Kendall, Conway, Rosenbek, & Gonzalez Rothi, 2003; Kendall, Nadeau, et al., 2006; Kendall, Rodriguez, Rosenbek, Conway, & Gonzalez Rothi, 2006; Kendall et al., 2008). We have shown that intensively delivered phonomotor treatment not only improves confrontation naming performance on trained words but, as predicted by the theory motivating it, also achieves generalization to naming of untrained words, some aspects of discourse production, and indicators of quality of life (Kendall, Brookshire, Oelke, & Nadeau, 2012; Kendall et al., 2008).

The phonomotor treatment program is motivated by two fundamental ideas. First, the process of word retrieval follows a two-step, bidirectional selection process using semantic, word form, and phonologic levels of knowledge (Dell, 1986; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997). Second, the specific tasks in the treatment program are guided by a parallel distributed processing model of phonology (Nadeau, 2001).

Dell's interactive activation theory of word processing (Dell, 1986; Dell et al., 1997) asserts that lexical knowledge is embedded in a network of three layers—semantic, lemma, and phoneme. Connections between the layers allow activation to spread (or cascade) bidirectionally from semantics to lemma to phoneme units, and likewise, from phoneme to lemma to semantic units (Dell et al., 1997, p. 805). For example, during confrontation naming of *dog*, visual

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processes identify the picture and activate corresponding semantic units with subsequent spread of activation to all layers (e.g., lemma and phonological) in the network. This cascading process may proceed from the bottom-up as well as top-down. Hence, initially activated phonological nodes will subsequently activate lemma nodes, which will then activate corresponding semantic nodes.

The spread of activation also influences the nodes that neighbor the target units at each linguistic level. For example, the semantic nodes activated with the visual presentation of *dog* will also trigger activation of semantically related items such as *cat*. As the spread of activation cascades to subsequent linguistic levels, related items at each level will be activated (i.e., lemma, phoneme), but to a lesser degree than the target nodes. Auditory input tasks, such as repetition, will activate acoustic representations associated with phonological nodes, which will cascade to lexical-semantic and articulatory-motor representations.

Regardless of the level of input, errors may occur at any linguistic level due to the spread of activation to neighboring nodes, decay of activation, and noise (Dell et al., 1997, p. 805). In other words, if the target phonological node (s) are inaccessible due to decay or noise, an error, potentially at any level in the network, could occur.

Although Dell's interactive activation model (Dell, 1986; Dell et al., 1997) provides theoretical support for the link between phonology and lexical semantics, the model lacks specificity regarding the nature of phonemic representations. Nadeau (2001) developed a detailed theory of phonology that describes the structure and processing of phonologic knowledge and representations. This theory further informed the development of this phonomotor treatment.

Nadeau's (2001) parallel distributed processing (PDP) model of phonology posits that phonemic representations are distributed and consist of large numbers of units that represent acoustic, articulatory-motor, and orthographic features. Knowledge within each domain (e.g., acoustic) is represented as patterns of activity that connect units. These connections are strengthened through learning. Thus, phonemic knowledge is represented as the pattern of activity throughout the association cortices. Within any domain, a representation corresponds to a specific pattern of activity of all of the units, hence the term *distributed representation*. Each unit within each of these domains is connected via interposed hidden units to many, if not most, of the units in the other domains. During learning, the strengths of the connections between the units are gradually adjusted so that a pattern of activity involving the units in one domain elicits the correct pattern of activity in the related units of another domain. Also, because the acoustic, articulatory-motor, and orthographic domains of the network are heavily interconnected, input into any domain (e.g., acoustic) of the network will lead to engagement of the related units in the other domains (e.g., articulatory motor). Consequently, the tasks in the present study's phonomotor treatment were selected to represent all domains of phonologic knowledge. For example, treatment tasks for the phoneme /*p*/ incorporated drills for orthography, auditory discrimination, and speech motor production.

Taken as a whole, the theoretical foundation for the treatment is as follows: Through the systematic training of phonemes (sounds) via acoustic, articulatory, visual, and orthographic tasks, the neural connectivity supporting individual phonemes and phoneme sequences will be enhanced in all corresponding domains. The treatment program mostly emphasizes input repetition as well as auditory and orthographic perception. Due to the bidirectional spread of activation within and between linguistic levels, these sound sequences provide the basis for words that represent conceptual semantics. Therefore, generalization from treating phonemes can be expected to improve naming of trained words as well as untrained words and discourse production, both immediately after treatment and continued beyond treatment termination.

Error analysis is a common technique employed in aphasia research to examine the psycholinguistic mechanisms responsible for word production. In particular, error profiles have been used to correlate with naming severity and functional lesion type (Dell et al., 1997; Schwartz & Brecher, 2000). First, with regard to naming severity and error types, nonnaming responses (such as omissions, circumlocutions, unrelated words, and nonwords) are attributed to more severe naming deficits, and responses related to the target word (e.g., semantic, phonologic, and mixed paraphasias) indicate an improvement in linguistic activation. Second, the weight-decay model (Dell et al, 1997; Schwartz & Brecher, 2000) is hypothesized to describe functional lesion type and error patterns separately from the severity of impairment. A *weight lesion* describes a disruption in the connection between nodes, which yields more semantically and phonologically unrelated errors. A *decay lesion* describes a disruption of the maintenance of node activation, which yields more semantically and phonologically related errors, as well as a mixture of these two error types.

In developing this treatment program, we were interested to know if overall accuracy of lexical-retrieval skills remained unchanged following treatment, and if unchanged, if the type of error would provide evidence of change in linguistic processing during word retrieval. In other words, would a change in error type indicate a change in processing at a specific linguistic level or across all levels? This information is essential as we continue to develop the phonomotor treatment protocol. Accuracy data alone is not sensitive enough to provide information on the relative effectiveness of the phonomotor treatment program. If the results of this study show a shift in error type, even if the accuracy is unchanged, then we would have preliminary support that the treatment program is indeed impacting linguistic processing mechanisms. In that case, factors such as intensity, dose, or stimuli could be evaluated as potential variables to improve linguistic mechanisms in order to reach higher activation and ensure correct production. To that end, we asked two research questions:

- Is there a significant difference between confrontation picture naming *accuracy* on trained and untrained items pre, immediately post, and 3 months post treatment?

- Is there a significant difference in *error type* between confrontation picture naming on trained and untrained items pre, immediately post, and 3 months post treatment?

Method

This project was approved by the University of Washington Institutional Review Board, and informed consent was obtained from each participant.

Participants

Ten individuals with chronic aphasia following left hemisphere damage due to cerebral vascular accident participated in this study. These participants were randomly selected from a larger ongoing treatment study. Participants were on average 54 years of age (*SD* = 15.24), had 16 years of education (*SD* = 3.06), and were on average 68 months post stroke onset (*SD* = 70.31). All exhibited aphasia, as measured by the Western Aphasia Battery (WAB; Kertesz, 1982); word retrieval deficits, as measured by the Boston Naming Test (BNT; Kaplan, Goodglass, Weintraub, & Segal, 1983); and impaired phonologic processing, as measured by the Standardized Assessment of Phonology of Aphasia (< 2 *SD*s below normal control performance) (SAPA; Kendall et al., 2010) The SAPA, consisting of three distinct subtests, has been used to detect impairment-level deficits in behaviors that have been strongly linked to phonology (e.g., reading, repetition, parsing/blending, auditory phonologic processing) in PWA. The SAPA has 151 items and has been validated with PWA and nonaphasic controls (Kendall et al., 2010).

Participants were excluded if they exhibited severe apraxia of speech as determined by perceptual assessment of rate, distorted substitutions, prosodic abnormalities, and effortful groping. Table 1 provides participant characteristics.

Outcome Measures

The primary outcome measure for this study was the accuracy of spoken word production during confrontation naming of 39 trained and 37 untrained nouns (see Treatment Stimuli below for details) that were randomly presented and administered 1 week pre treatment, 1 week immediately post treatment, and 3 months post treatment. All items were presented as color photographs via PowerPoint on a computer monitor. No time limit to respond was enforced. Participants' confrontation naming responses were digitally recorded and then were coded for overall accuracy and error type. One visual cue (e.g., "Look at where the arrow is pointing to in the picture") and one specificity cue (e.g., if the participant responds *shoe* for target *boot*, he or she is asked to be more specific as to type of footwear) were allowed, and the final response was coded as correct or incorrect. Incorrect responses were coded as phonologic (additions, substitutions, distortions, distorted substitutions, transpositions, omissions), semantic (related), unrelated, mixed (phonologic + semantic), omissions (no response, with semantic description), or neologisms (Dell et al., 1997; Schwartz & Brecher, 2000).

Reliability of outcome measure scoring. Interrater reliability on 10% of the corpus resulted in 97.6% reliability on accuracy scores and 73.4% reliability on error type coding. The error type coding reliability score can largely be attributed to differences in coder interpretation of what constituted the participants' "final" response.

Data Analysis

Paired-samples *t* tests compared confrontation naming accuracy and error type on all responses pre, immediately post, and 3 months post treatment. Error types were combined into broad categories (i.e., semantic, phonologic, unrelated, mixed, omissions, and nonwords) for general consistency with the error analysis literature.

Table 1. Study participants' characteristics.

				WAB AQ (out of 100)			**BNT (out of 60)**			**SAPA (out of 151)**		
Participant	**Age**	**Months post stroke**	**Years of education**	**Pre**	**Post**	**3 months post**	**Pre-**	**Post-**	**3 months post**	**Pre**	**Post**	**3 months post**
1	50	21	16	87.5	88.6	87.1	37	42	47	96	106	119
2	48	16	13	94.6	94.4	95.4	52	49	52	131	137	135
3	27	17	13	51.1	70.1	70.3	44	50	45	74	91	80
4	67	162	14	84.5	86.9	89.8	36	38	42	94	106	105
5	53	81	19	63.9	68.7	70.8	13	28	15	64	74	68
6	57	24	16	82	87.2	84.1	31	36	41	102	116	112
7	72	211	18	69.8	80.6	65.4	34	26	19	76	76	92
8	67	104	16	81.1	85.7	80.5	56	57	46	103	119	115
9	68	14	23	92	94.4	93.2	57	56	56	109	118	117
10	33	31	15	78.2	83.5	80.4	31	40	40	65	85	85

Note. WAB AQ = Western Aphasia Battery (Kertesz, 1982) aphasia quotient; BNT = Boston Naming Test (Kaplan, Goodglass, Weintraub, & Segal, 1983); SAPA = Standardized Assessment of Phonology in Aphasia (Kendall et al., 2010).

Treatment Stimuli

Stimuli consisted of all English phonemes in isolation, 72 nonwords, and 39 real words of low phonotactic probability and high neighborhood density. The Appendix provides a list of the trained and unrained real-word stimuli. The choice to use low phonotactic probability stimuli was based on the concept that training atypical exemplars of a domain will increase knowledge relevant to *both* atypical *and* typical exemplars, whereas training only typical exemplars benefits *only* typical exemplars (Kiran & Thompson, 2003; Plaut, 1996) and can be related to principles of neural network function captured in PDP models (Thompson & Shapiro, 2007; Nadeau, 2012). Storkel, Armbruster, and Hagan (2006) provided empirical support for this concept in the domain of phonology. The choice to use stimuli with high neighborhood density was made to maximize the number of word concepts that might engage trained phonemes and phonological sequences.

Phonotactic probability was calculated using methods similar to Vitevitch and Luce (1999). Two measures were used to determine phonotactic probability: (a) positional segment frequency (i.e., how often a segment occurs in a position in a word) and (b) sum biphone frequency (i.e., segment-to-segment probability). 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). 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. Phonotactic probability and neighborhood density were computed for stimuli and were categorized as high or low based on a median split (Storkel et al., 2006). Real word stimuli were controlled for frequency, imageability, age of acquisition, syllable number, syllable complexity, and semantic category.

Treatment Procedure

The PWA received 60 hr of phonomotor treatment (1-hr treatment sessions, 2 sessions/day, 5 days/week for 6 weeks) delivered by a certified speech-language pathologist who had received 60 hr of training on the treatment protocol. This intensive, multimodal treatment program was divided into two stages. Stage one focused on sounds in isolation, and stage two focused on sounds in various combinations.

The goal of stage one was to engage individual sounds by teaching (a) motor movements and descriptions with the use of a mirror and therapist and participant feedback (e.g., the tip of your tongue is behind your front teeth and taps to make the sound /t/); (b) perceptual discrimination (e.g., do /t/ and /d/ sound the same or different?); (c) production (e.g., repeat after me…say /t/); and (d) grapheme-to-phoneme correspondences (e.g., letter for each sound is displayed). The goal of stage two was to extend the skills acquired in stage one to various phoneme sequences. Production, perception, and graphemic tasks remained the same in this second stage, with the one difference that sounds would be produced in combinations rather than isolation. Training progresses hierarchically (e.g., VC, CV, CVC, CCV, VCC, CCVC, CVCC, CCVCC). Upon mastery of 1-syllable treatment stimuli, 2-syllable stimuli are introduced and trained. The goal of treatment is to strengthen and improve each participant's phonological awareness to the extent that he or she is able to repeat, read, spell, parse, and blend all treatment stimuli by the end of the 6-week treatment program. Both real-word and nonword stimuli were trained using the same procedures detailed below.

Stage 1

Exploration of sounds. The participant was shown a mouth picture of a sound and was asked to look in the mirror and repeat after the therapist to make the sound. Knowledge of results was initially given at 100% frequency following each production and then was faded to 30% across trials. Following production, the therapist asked the participant what he or she saw and felt when the sound was made. Socratic questioning was used to enable the participant to "discover" the auditory, visual, articulatory, and tactile/kinesthetic attributes of the sounds (e.g., "What do you feel when you make that sound?").

Motor description. A description of each sound was provided. The therapist described what articulators were moving and how they move (e.g., "for /p/ the lips come together and blow apart, the voice box is turned off, the tongue is not moving"). The participant was asked to repeat the sound and then was asked to describe how the sound was made. For example, "Do your lips or tongue move to make that sound?"

Perception tasks. The therapist made a sound (e.g., /p/) and asked the participant to choose that sound from an array of mouth pictures (e.g., /f/, /g/, /p/).

Production tasks. Productions of sounds were elicited auditorily (repetition), visually (mouth picture), and via motor description (e.g., "make the sound where your lips come together and blow apart"). Socratic questioning was used for correct and incorrect responses. For example, "you said /b/ — is that the sound where your tongue taps the roof of your mouth?"

Graphemic tasks. Graphemic tiles representing sounds were placed on the table with the mouth pictures. The participant was asked to select a single grapheme and place it on a picture that represented that sound. When the participant was finished, the therapist used Socratic questioning (e.g., "this letter says /f/, does this picture represent /f/?"). If the production was correct, the therapist moved to the next letter tile; if the production was incorrect, the therapist set aside the letter tile and moved to the next tile. After the participant was able to correctly match graphemes to mouth pictures, graphemes were then used in the production and perception tasks for the remainder of the treatment program.

Stage 2

Perception and graphemic task. The therapist produced a real-word or nonword sound combination (e.g., VC or VCC-VC) and then asked the participant to arrange mouth pictures or graphemes to depict the target. For example, if the participant heard the VC *ip*, he or she would select the graphemes /i/ and /p/.

Production and graphemic task. The therapist showed either mouth pictures or grapheme tiles and asked the participant to produce the sounds within a real word or nonword individually and then blended together. For example, the participant would say "/p/ /ee/ /f/ …that says /peef/." In this example, the therapist would say "You said /peef/. Does that match these letters?" Next, the therapist would change one sound in the word (e.g., /peef/ changed to /feef/). The participant was cued to say the old word by touching each sound individually and then identifying the new sound and blending the new word (e.g., the old word says /p/ /ee/ /f/, /p/ is removed and /f/ is added, the new word now says /feef/). One sound change within a word was made for a series of 5–10 nonwords.

Results

Research Question 1 – Accuracy

Results of paired-samples *t* tests on the accuracy of trained and untrained items are outlined below and illustrated in Figure 1.

Trained items. Results of paired-samples *t* tests showed statistically significant improvements in accuracy when comparing pre- and immediate posttreatment probes ($p = .001$; $\alpha = .025$ after multiple comparison correction) and pre- and 3-month posttreatment probes ($p = .001$) of the trained confrontation naming items. Mean accuracy pre treatment was 68% (*SD* = 20%), immediately post treatment was 87% (*SD* = 13%), and 3 months post treatment was 83% (*SD* = 16%).

Untrained items. Results of paired-samples *t* tests showed no statistically significant differences in accuracy when comparing pre- and immediate posttreatment probes ($p = .551$; $\alpha = 025$ after multiple comparison correction) and pre- and 3-month posttreatment probes ($p = .128$) of the untrained confrontation naming items. Mean accuracy pre treatment was 71% (*SD* = 17%), immediately post treatment was 73% (*SD* = 17%) and 3 months post treatment was 75% (*SD* = 18%).

Research Question 2 – Error Types

Results of paired-samples *t* tests on error types (i.e., semantic, phonologic, unrelated, mixed, omission, and neologism) showed a near-significant decrease in omissions when comparing pre- and immediate posttreatment probes ($p = .055$; $\alpha = 01$ after multiple comparison correction) on the trained confrontation naming items. Other pre-, immediate post-, and 3-month posttreatment comparisons of trained item error types were not significant.

Results of paired-samples *t* tests on all error types combined showed a near-significant increase in mixed errors when comparing pre- and immediate posttreatment probes ($p = .089$; $\alpha = .01$ after multiple comparison correction) on the untrained confrontation naming items. Otherwise, pre-, immediate post-, and 3-month posttreatment comparisons of untrained item error types were not significant.

Mean error proportions for both the trained and untrained items are outlined below and illustrated in Figures 2 and 3.

Trained items. The percentage of semantic errors pre treatment was 44% (*SD* = 18%); post treatment, 50% (*SD* = 40%) ($p = .639$); and 3 months post treatment, 5% (*SD* = 40%) ($p = .151$). The percentage of phonologic errors pre

Figure 1. Pre-, immediate post-, and 3-month posttreatment accuracy data for the trained and untrained confrontation naming stimuli. Statistically significant differences between probe time points are shown with brackets ($p < .025$).

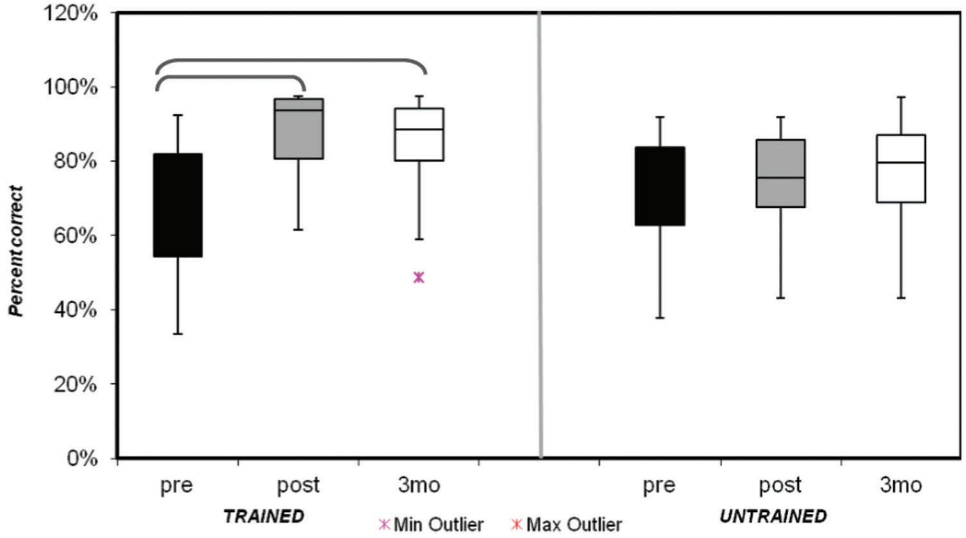
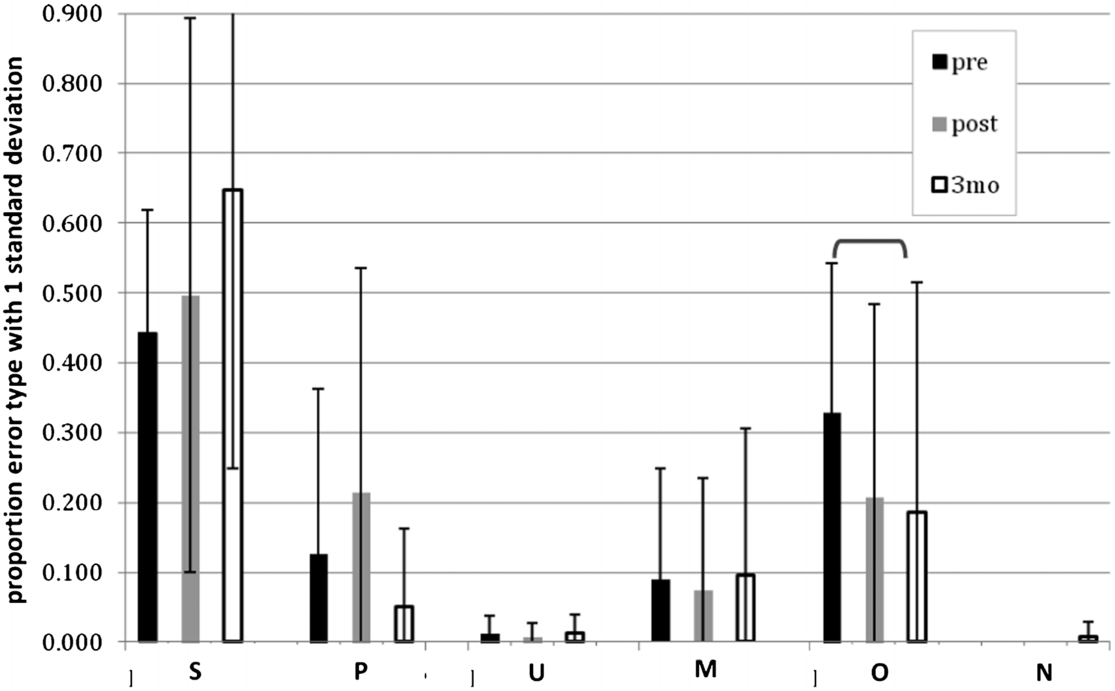
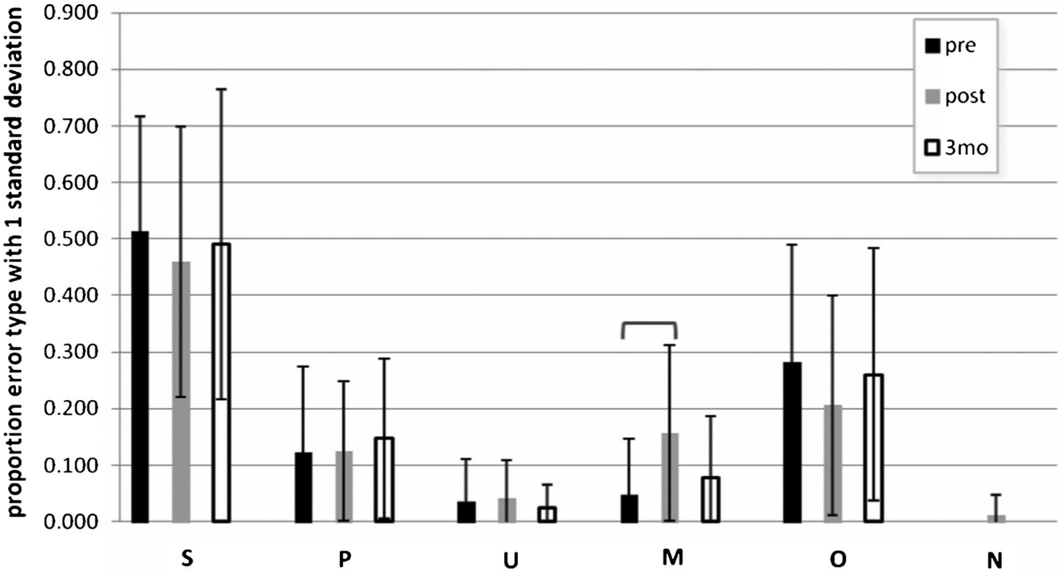


Figure 2. Proportion of error type (with 1 *SD*) for trained stimuli. Error types: semantic (S), phonologic (P), unrelated (U), mixed (M), omission (O), neologism (N). Near statistically significant difference between probe time points in error type (decrease in omissions) is shown with a bracket ($p < .01$).



treatment was 13% (*SD* = 2%); post treatment, 2% (*SD* = 32%) ($p = .242$); and 3 months post treatment, 5% (*SD* = 11%) ($p = .256$). The percentage of unrelated errors pre treatment was 1% (*SD* = 3%); post treatment, <1% (*SD* = 2%) ($p = .665$); and 3 months post treatment, 1% (*SD* = 3%) ($p = .927$). The percentage of mixed errors pre treatment was

Figure 3. Proportion of error type (with 1 *SD*) for the untrained stimuli.



9% (*SD* = 16%); post treatment, 8% (*SD* = 16%) (*p* = .839); and 3 months post treatment, 10% (*SD* = 21%) (*p* = .948). The percentage of omission errors pre treatment was 33% (*SD* = 21%); post treatment, 21% (*SD* = 28%) (*p* = .016); and 3 months post treatment, 19% (*SD* = 33%) (*p* =.211). The percentage of neologism errors pre treatment was 0%; post treatment, 0%; and 3-months maintenance, <1% (*SD* = 2%) (*p* = .343).

Untrained items. The percentage of semantic errors pre treatment was 51% (*SD* = 21%); post treatment, 46% (*SD* = 24%) (*p* = .286); and 3 months post treatment, 49% (*SD* = 28%) (*p* = .756). The percentage of phonologic errors pre treatment was 12% (*SD* = 15%); post treatment, 13% (*SD* = 12%) (*p* =.967); and 3 months post treatment, 15% (*SD* = 14%) (*p* = .574). The percentage of unrelated errors pre treatment was 4% (*SD* = 8%); post treatment, 4% (*SD* = 6%) (*p* = .871); and 3 months post treatment, 2% (*SD* = 4%) (*p* = .725). The percentage of mixed errors pre treatment was 5% (*SD* = 10%); post treatment, 16% (SD 16%) (*p* = .089); and 3 months post treatment, 8% (*SD* = 11%) (*p* = .504). The percentage of omission errors pre treatment was 28% (*SD* = 21%); post treatment, 21% (*SD* = 20%) (*p* = .220); and 3 months post treatment, 26% (*SD* = 22%) (*p* = .508). The percentage of neologism errors pre treatment was 0%; post treatment, 1% (*SD* = 4%) (*p* = .343); and 3 months post treatment, 0%.

Discussion

Our results suggest that intensive phonomotor treatment made a significant improvement in the lexical-retrieval abilities of PWA on trained items, and these skills were maintained 3 months after treatment. Overall, the most prevalent error types on trained items, both before treatment began and after treatment was terminated, were omission and semantic errors, and the type of error that was most affected by treatment was omission. Although accuracy on untrained items did not change significantly from pre to immediately post or 3 months post treatment, we saw an increasing trend in mixed errors from pre to immediately post treatment. This finding suggests a small but notable shift in linguistic processing, which may account for greater activation within and between the phonological and semantic levels. The accuracy and error type results taken together indicate that the neural connectivity supporting individual phonemes and phoneme sequences was enhanced. Generalization from treating phonemes in isolation, and in real-word and nonword sequences, resulted in improved naming abilities, as evidenced by a reduction of anomic responses. This observed change in linguistic processing is best explained through a bidirectional spread of activation within and between linguistic levels.

Accuracy

The improvement in accuracy observed in trained items was expected, has been widely reported in the aphasia treatment literature, and supports our hypothesis. The lack of generalization to the untrained items is due to minimal improvement when comparing pre- (71% accuracy) and post- (73% immediate, 75% 3 months) treatment accuracy scores. Accuracy data from the larger group (*n* = 20) treatment study have been analyzed (Kendall et al., 2012), where confrontation naming accuracy of untrained items significantly improved following treatment: pretreatment accuracy 64%, 70% immediately post treatment (*p* = .001), and 71% 3 months later (*p* = .033). So, the difference between the current investigation of *n* =10, and the larger group of *n* = 20, is due to the lower pretreatment accuracy scores of the larger group compared to the current group.

Error Types

The higher rates of pretreatment semantic and omission errors, relative to phonologic, unrelated, mixed, and neologism errors, indicate that our small group of individuals also had difficulty accessing the lemma (Dell et al., 1997) in addition to their phonologic impairment. Semantic errors are also the most common errors made by unimpaired speakers in picture naming (Dell et al., 1997). Because semantically related words share feature units, activation is sent from the target unit to semantic neighbors. If there is noise in the system, the incorrect semantic item may be selected (Dell et al., 1997). Omitted responses, as well as omissions with semantic description (i.e., circumlocutions), may occur when candidate items for selection at the level of semantics do not reach an activation threshold (Dell, Lawler, Harris, & Gordon, 2004).

There was a shift in error types following treatment. Specifically, a decrease in omission errors and an increase in semantic errors for trained items were observed 3 months post treatment. This shift was especially notable in participants who improved on the BNT. Of the six participants who improved on the BNT (pre to 3 months post), five individuals showed an increase in semantic errors and a decrease in omissions at 3 months post treatment. These findings lend support for improved activation of semantic-level processing and could also depend on the characterization of impairment severity and functional lesion type. The reduction of omission errors following treatment for the trained items is consistent with movement from a more severe naming deficit to a milder form. Further, as noted in the weight-decay model (Dell et al., 1997; Schwartz & Brecher, 2000), patterns in error production may change depending on severity or on one of two types of lesions in the model. A weight lesion is described as impaired connections between nodes, and a decay lesion is described as impaired maintenance of node activation (Dell et al., 1997; Schwartz & Brecher, 2000). Weight lesions promote errors where the selected word does not correspond to the semantics or where the phonemes do not correspond to the selected word. On the other hand, because decay lesions allow for transmission of activation, the choice word, even when erroneous, is constrained by the semantic network (Schwartz & Brecher, 2000). Thus, the individuals in this group more than likely exhibited a decay lesion.

An increase in mixed errors when comparing pre- and immediate posttreatment confrontation naming on untrained items may be indicative of an increase of activation in the phonological level and the semantic level. These errors are often characterized as a "mixed-error effect" (Schwartz, Dell, Martin, Gahl, & Sobel, 2006, p. 231; see also Martin, Gagnon, Schwartz, Dell, & Saffran, 1996) and are indicative of the interrelatedness of phonological and semantic levels of processing. In other words, the phonological and semantic levels interact to contribute to these types of errors. Furthermore, mixed errors may indicate strong phonological feedback during word retrieval (Dell et al., 2004), wherein the phonological target is activated along with its neighboring nodes. Mixed errors and semantic errors are reportedly present along the aphasia severity continuum (Schwartz & Brecher, 2000). These errors may occur regardless of severity, or they may not be present at all (Dell et al., 1997).

Future Directions

Although our results point to improvements in word-retrieval accuracy on trained items and some shifts in linguistic processing for both trained and untrained items, additional analyses are required to fully understand how phonomotor treatment generalizes and influences processing across linguistic levels. Future analyses may include accuracy and error type data from all study participants (n = 30), providing additional power for further analyses on generalization to untrained items. Additionally, due to the high variability in error types observed in this group, all participants may be analyzed categorically or individually, rather than as one group, to provide more specific information on individual shifts in processing. For example, we may conduct detailed analyses of errors produced during pretreatment probes and then categorize participants by trends in error type, or weight/decay lesion type, for subsequent posttreatment analyses. It would be interesting to know how these results relate to phonologic treatment delivered in a less intense (e.g., distributed) treatment schedule. Additional information on improvement in linguistic processing following phonomotor treatment may also be obtained through an analysis of confrontation naming reaction times of correct responses, as well as an analysis of pre- versus posttreatment self-cuing strategies.

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Appendix

Trained and untrained real-word stimuli

Trained stimuli	Untrained stimuli
bow	toy
hay	tire
leather	wire
jury	iron
ache	age
shadow	baby
boot	valet
fig	lady
maze	whip
mop	beef
heater	birth
plane	ditch
half	wheel
tower	chauffeur
teacher	laughter
feeder	turkey
gravy	fisher
day	razor
song	jeans
ivy	clover
shoulder	pie
treasure	fur
lawyer	knee
movie	fire
ape	egg
itch	genie
polo	halo
lasso	meadow
knob	witch
cave	knot
bird	shower
jail	break
owl	bride
ladder	bruise
father	tiger
jockey	speaker
level	poem
ranger	
gray	