# The Influence of Phonomotor Treatment on Word Retrieval: Insights from Naming Errors

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# Abstract

**Purpose**: An increasing number of anomia treatment studies have coupled traditional word retrieval accuracy outcome measures with more fine-grained analysis of word retrieval errors to allow for more comprehensive measurement of treatment-induced changes in word retrieval. The aim of this study was to examine changes in picture naming errors after Phonomotor Treatment.

**Method**: Twenty-eight individuals with aphasia received 60 hours of Phonomotor Treatment, an intensive, phoneme-based therapy for anomia. Confrontation naming was assessed pre-treatment, immediately post-treatment, and 3 months post-treatment for trained and untrained nouns. Responses were scored for accuracy and coded for error type, and error proportions of each error type (e.g., semantic, phonological, omission, etc.) were compared pre - versus post-treatment and pre- versus 3 months post-treatment.

**Results**: The group of treatment participants improved in whole word naming accuracy on trained items and maintained their improvement. Treatment effects also generalized to untrained nouns at the maintenance testing phase. Additionally, participants demonstrated a decrease in proportions of omission and description errors on trained items immediately post-treatment.

**Conclusions**: Along with generalized improved in whole word naming accuracy, results of the error analysis suggest that a global (i.e., both lexical-semantic and phonological) change in lexical knowledge underlies the observed changes in confrontation naming accuracy following Phonomotor Treatment.

*Key words*: error analysis, Phonomotor Treatment, aphasia, word retrieval, anomia

The treatment of anomia, the most ubiquitous aphasia symptom, is central to aphasia therapy. Typically, the effectiveness of aphasia treatments that target anomia is examined by measuring naming accuracy of trained items and generalization to untrained targets. The primary expected outcome of most anomia treatment programs is improved naming accuracy of words directly trained in therapy, and optimally, generalization of improvement to words outside the focus of therapy. These measures are useful, but provide grossly limited information about the nature of treatment-induced changes in the linguistic network. Although they can tell us whether the severity of a naming impairment has changed as a result of treatment, accuracy-based measures cannot tell us about the nature of recovery (for example, whether a given treatment strengthened semantic or phonological access). Information about the nature of linguistic improvement can help determine the types of participant profiles that may be a good match for a given treatment program, as well as inform theoretical models of language learning and rehabilitation (e.g., parallel distributed processing models). The purpose of the present study was to couple traditional whole word accuracy measures with a detailed word retrieval error analysis in order to better understand the effects of an intensive phoneme-based therapy for anomia (Phonomotor Treatment) on word retrieval.

Though word retrieval error analyses are just beginning to be included as secondary outcome measures in aphasia treatment studies, their use as measures of linguistic integrity/impairment in experimental studies of word retrieval in aphasia has a longer history. Prior to studying word retrieval errors of individuals with aphasia, studies of word retrieval errors with typical speakers were used to investigate the nature of lexical retrieval (e.g., Fromkin, 1973; Garret, 1975, Shattuck-Hufnagel, 1979). Several decades later, initial studies of word retrieval errors in individuals with aphasia (e.g., Martin, Roach, Brecher, & Lowery, 1998;

Nickels & Howard, 1994, 1995, etc.) increased our understanding of the possible patterns of lexical breakdown that occur in aphasia as well as the constraints of aphasic word retrieval errors (e.g., individuals with aphasia make more errors than typical speakers, but their errors rarely differ from errors found in typical word production, Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Silkes, McNeil, & Drton, 2004). Thus, these studies have contributed to our understanding of both disordered and typical word production. Contemporary studies of word retrieval errors in individuals with aphasia have extended this work in a variety of ways, such as by looking at neural bases of specific word retrieval errors (Chen, Middleton, & Mirman, 2018; Fridriksson, Baker, & Moser, 2009), using behavioral word retrieval errors and computer modeling to obtain a precise understanding of the nature of word retrieval impairment (e.g., Dell, Lawler, Harris, & Gordon, 2004; Foygel & Dell, 2000; Walker & Hickock, 2016, Walter, Hickok, & Fridriksson, 2018), and examining word retrieval errors in order to better understand the subtypes of primary progressive aphasia (Dalton, Shultz, Henry, Hillis, & Richardson, 2018). Halai, Woollams, and Lambon Ralph (2018) combined several of these approaches by incorporating patients' naming errors, performance on a cognitive-linguistic battery, and lesion profiles in order to obtain a holistic model of language processing impairments in aphasia. These investigations demonstrate the diverse utility of word retrieval error coding and echo the need to consider error types along with accuracy scores on classic language measures (e.g., confrontation picture naming) in order to gain a more complete picture of an individual's language processing impairment.

Extant studies have advocated such coupling of picture naming error analyses with more traditional language processing measures (e.g., word retrieval naming accuracy) (Capitani & Laiacona, 2004; Grima & Franklin, 2017; Walker, Hickok, & Fridriksson, 2018). These fine-grained analyses provide a sensitive window into linguistic processing at a given point in time, and may be a useful measure of change after language intervention. Beyond naming accuracy, word retrieval error analyses appear to provide insights about the nature of linguistic recovery following anomia treatment. Evidence supporting the use of word retrieval error analyses to measure anomia treatment responsiveness is narrow but growing steadily. For example, Bose (2013) treated an individual with “jargon” aphasia with a phonological component analysis therapy (a treatment that trained awareness of word rhymes, initial and final sounds, and syllables). Aside from an improvement in trained words, they found a decrease in the number of neologisms as well as an increase in phonological similarity between target words and nonwords produced after treatment, indicating improved phonological access. These changes in word retrieval errors were found on an untrained word retrieval measure (the Philadelphia Naming Test; Roach, Shwartz, Martin, Grewal, & Brecher, 1996), and, because they occurred in the absence of improved accuracy on untrained words (i.e., lack of traditional generalization), the authors argued for the importance of including this sensitive measure in order to obtain a more complete picture of treatment recovery.

Other small case series anomia treatment studies have also used error analyses to gain a more thorough understanding of mechanisms behind treatment-induced changes in naming performance. Gordon (2007) treated two individuals with two semantic treatment paradigms, one focused on traditional semantic feature analysis and the other on contextual word associations. Each participant received both treatments. Errors were tracked prior to and after both treatments were completed, and the changes suggested more efficient and effective activation of the word production network following treatment: participant 1 demonstrated errors that were more phonologically similar to target words following treatment completion, while participant 2 demonstrated a decrease in circumlocution and omission errors. Similarly, Kiran and Thompson

(2003) treated four individuals with a semantic feature analysis treatment paradigm, and interpreted an increased proportion of semantically and phonologically related errors in their participants as greater efficiency in the word retrieval network after treatment.

Because the aforementioned studies were either single case or small case series investigations, their error analyses were largely descriptive in nature. Several recent anomia treatment studies have performed language error analyses with a relatively larger number of participants. Hashimoto, Widman, Kiran, and Richards (2013) used a crossover design to compare a semantic treatment that emphasized word category membership with a treatment that emphasized semantic features. Six of their eight participants improved on trained items, with no obvious advantage for one treatment condition over another when analyzing response accuracy; however, a difference between groups was found when considering naming errors. Both treatments were associated with a decrease in omission errors, while only the categorical treatment was associated with an increase in semantic errors, demonstrating a potential difference in treatment-induced changes in the linguistic network that would have been missed with analyses focused only at the whole word accuracy level. Ross, Johnson, and Kiran (2017) introduced a novel system for coding reading and writing errors for individuals undergoing treatment for alexia and agraphia, and identified a variety of error evolution patterns in their participants through their thorough qualitative analysis. The authors emphasized that because several of the eight participants demonstrated clear changes in error profiles in the face of modest changes in accuracy-based measures, their error analysis system provided a more sensitive measure for treatment responsiveness, and may be useful for guiding future interventions. For example, one participant demonstrated a decrease in perseverative errors following treatment, and the authors suggested that future treatment should make use of highly distinct stimuli and tasks in order to prevent perseverative errors.

Several larger studies have extended error analyses further, allowing for more robust group-level analyses of a larger number of error types, as well as sub-group analyses that investigate error evolution in individuals with milder versus more severe aphasia. For instance, a study focused on Phonomotor Treatment (Kendall, Oelke, Brookshire, & Nadeau, 2015), an intensive phoneme-based therapy for anomia, coupled group-level error analyses with more traditional whole word accuracy measures. Kendall, Pompon, Brookshire, Minkina, and Bislick (2013) examined improvement in lexical retrieval via confrontation naming error profiles of 10 people with aphasia. In this study, participants improved in their ability to name trained items and maintained these improvements 3 months after treatment. Additionally, an analysis of word retrieval error type showed a trend towards a decrease in the number of omission errors on trained words and a trend towards an increase in the number of mixed errors on untrained words. In a larger follow-up trial with 24 people with aphasia (Minkina et al, 2016), participants demonstrated improvement in naming accuracy of trained words both immediately following treatment and at 3 months post-treatment, as well as improvement in naming of untrained words at 3 months post-treatment. Furthermore, participants’ naming errors included trends towards a significant decrease in the number of omissions immediately following treatment for trained items, as well as trends towards a decrease in omissions in both trained and untrained items 3 months post-treatment. A significant decrease in omission errors on trained items was found for the subgroup of participants with more severe anomia. Together, these results suggested a holistic shift in the word retrieval network, encompassing changes in both lexical-semantic and phonological knowledge.

The goal of the present study was to extend our prior work (Kendall et al., 2013; Minkina et al., 2016) with a new, larger group of individuals (n = 28) who participated in a Phase II Phonomotor Treatment Program. In the present study, we used a widely accepted error coding structure from the Philadelphia Naming Test (PNT; Roach et al., 1996) in order to explore the evolution of naming errors in our largest participant sample to date. This extensive coding structure allows for more precise and less ambiguous error coding decisions than in our previous work (e.g., the PNT provides comprehensive guidelines for determining phonological similarity of the target and actual naming response). Consistent with our earlier studies, we used Dell's Interactive Activation (IA) model (Dell et al., 1997) to conceptualizes the errors observed in our participant sample. The model posits three levels of bidirectionally connected processing nodes that govern word retrieval (semantic, word/lemma, and phonological). Word retrieval precedes through two stages: lemma (or word form) retrieval and phonological retrieval. Overly rapid decay of node activation or weak connections among nodes can lead to the production of an incorrect word, such as a word with a relationship to the target word (e.g., phonological errors such as dog→/dɔd/, formal errors such as dog→bog, semantic errors such as dog→cat, or mixed errors such as dog→frog), a word without a clear semantic or phonological relationship to the target (unrelated error), or a non-response (omission error). The Philadelphia Naming Test's coding scheme was developed in context of Dell's word retrieval model.

Specifically, the present study investigated the influence of Phonomotor Treatment on target-related errors, target-unrelated errors, and omission errors in the context of changes in more traditional accuracy-based word retrieval measures. We focused on changes occurring immediately after treatment completion and at a 3 months maintenance testing time point for both trained and untrained lexical items. The following research questions were asked:

1) Is there a significant difference between confrontation picture naming accuracy pre-treatment versus immediately post-treatment, and pre-treatment versus 3 months post-treatment for trained, untrained (linguistically related) and untrained (linguistically unrelated) stimuli?
2) Is there a significant difference in the proportions of target related errors (formal, mixed, phonologically related nonword, and semantic errors) pre-treatment versus immediately post-treatment, and pre-treatment versus 3 months post-treatment for trained, untrained (linguistically related) and untrained (linguistically unrelated) stimuli?
3) Is there a significant difference in the proportions of target unrelated errors (description, phonologically unrelated nonword, unrelated, and miscellaneous errors) pre-treatment versus immediately post-treatment, and pre-treatment versus 3 months post-treatment for trained, untrained (linguistically related) and untrained (linguistically unrelated) stimuli?
4) Is there a significant difference in the proportion of omission errors pre-treatment versus immediately post-treatment, and pre-treatment versus 3 months post-treatment for trained, untrained (linguistically related) and untrained (linguistically unrelated) stimuli?

## Method

This project was approved by the University of Washington Institutional Review Board and Veterans Affairs Medical Center Puget Sound, and informed consent was obtained from each participant.

## Participants

Participants were recruited through the VA Puget Sound Health Care System (Seattle and American Lake), and the University of Washington/Portland State University Aphasia Registry and Repository, as well as area speech-language pathology clinics.

All participants presented with chronic aphasia (> 6 months post-onset) due to left-hemisphere damage after stroke. Using computed tomography (CT) or magnetic resonance imaging (MRI) scans, lesion type, locus, and extent of brain damage were characterized and interpreted to determine study eligibility. Study inclusion required that participants demonstrate aphasia with anomia, determined via performance on the Comprehensive Aphasia Test (CAT; Swinburn, Porter & Howard, 2004) and the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 2001), in addition to clinical observations on both standardized tasks and during conversational speech. In addition, participants had to demonstrate sufficient auditory comprehension to follow basic directions (as determined by performance on the Comprehension of Spoken Language subtests of the CAT). Participants with concomitant mild to moderate apraxia of speech were included. Individuals were excluded if they exhibited untreated depression, degenerative neurological disease, chronic medical illness, uncorrected impairment of vision or hearing, or severe apraxia of speech (as evidenced by frequent occurrences of the following characteristics, noted on the majority of utterances and severe enough to impact intelligibility:  slowed rate, distortions, distorted substitutions and prosodic abnormalities).

Participants included 28 individuals (15 males, 13 females). All individuals had chronic aphasia following left hemisphere damage due to cerebral vascular accident and were part of an ongoing treatment study (Kendall, Moldestad, Allen, Torrence, & Nadeau, under revision). Participants were, on average, 63.3 years of age (*SD* = 10.6), had 14.3 years of education (*SD* =

**Table 1.** *Participant Characteristics and Standardized Test Scores*

| **ID** | **Age** | **Sex** | **Edu (years)** | **Handedness** | **YPO** | **BNT (out of 60)** | **Comprehension of Spoken Language T-Score (CAT)** | **RCPM (out of 36)** |
|---|---|---|---|---|---|---|---|---|
| PM01PDX | 71 | F | 15 | R | 1.42 | 49 | 59 | 35 |
| PM01SEA | 46 | F | 16 | R | 1.25 | 23 | 58 | 28 |
| PM02PDX | 59 | F | 16 | R | 5.25 | 42 | 50 | 33 |
| PM02SEA | 67 | M | 12 | R | 2.75 | 46 | 60 | 29 |
| PM03SEA | 70 | F | 12 | R | 6.75 | 6 | 39 | 23 |
| PM04PDX | 40 | F | 16 | R | 1.83 | 5 | 51 | 36 |
| PM04SEA | 59 | M | 18 | R | 2.25 | 6 | 54 | 32 |
| PM05PDX | 71 | F | 14 | R | 0.83 | 36 | 58 | 31 |
| PM05SEA | 65 | M | 16 | R | 8.42 | 4 | 44 | 34 |
| PM06PDX | 73 | M | 16 | R | 2.33 | 6 | 49 | 28 |
| PM06SEA | 73 | F | 13 | R | 2.5 | 12 | 50 | 34 |
| PM07PDX | 67 | M | 16 | R | 4.17 | 20 | 53 | 32 |
| PM07SEA | 46 | M | 13 | L | 7.08 | 14 | 45 | * |
| PM08PDX | 59 | F | 12 | R | 3.67 | 0 | 35 | 26 |
| PM08SEA | 71 | F | 16 | R | 3.67 | 41 | 52 | 34 |
| PM09PDX | 90 | F | 12 | L | 6.42 | 26 | 58 | 29 |
| PM09SEA | 63 | M | 13 | R | 4 | 32 | 45 | 35 |
| PM10PDX | 60 | M | 14 | L | 2.75 | 2 | 46 | 19 |
| PM11PDX | 46 | M | 11 | R | 24.8 | 3 | 41 | 35 |
| PM11SEA | 74 | F | 14 | R | 0.92 | 3 | 44 | 25 |
| PM12PDX | 63 | M | 16 | L | 2 | 2 | 50 | 32 |
| PM12SEA | 62 | M | 16 | R | 0.83 | 46 | 58 | 35 |
| PM13SEA | 50 | M | 12 | R | 2.08 | 1 | 52 | 29 |
| PM14SEA | 67 | F | 16 | R | 1.67 | 39 | 45 | 32 |
| PM15SEA | 70 | M | 12 | R | 4.42 | 32 | 56 | 21 |
| PM16SEA | 66 | F | 12 | R | 9.42 | 40 | 58 | 22 |
| PM17SEA | 65 | M | 14 | L | 1.42 | 52 | 55 | 22 |
| PM18SEA | 59 | M | 18 | L/R | 4.17 | 16 | 47 | 33 |
| **Ave** | 63.29 |  | 14.32 |  | 4.25 | 21.57 | 50.43 | 29.78 |
| **SD** | 10.61 |  | 2.02 |  | 4.66 | 17.84 | 6.64 | 4.99 |

*Edu = Education*; *YPO = Years Post Onset; BNT = Boston Naming Test; CAT = Comprehensive Aphasia Test; RCPM = Raven's Coloured Progressive Matrices*; * indicates missing data

2.0), and were 4.3 years post stroke onset (*SD* = 4.7). See Table 1 for participant demographics and performance on standardized tests, including the Boston Naming Test (Kaplan et al., 2001), the Comprehension of Spoken Language portion of the Comprehensive Aphasia Test (Swinburn et al, 2004), and Raven's Coloured Progressive Matrices (Raven, 1986).

**Table 2.** *Treatment and Generalization Stimuli*

| Sounds in Isolation | | Real Word Nouns | | | | Nonwords | |
|---|---|---|---|---|---|---|---|
| **Trained** | | **Trained** | **Untrained, Related** | **Untrained, Unrelated** | | **Trained** | |
| IPA | Graphemes | *1 syllable:* | *1 syllable:* | *High Frequency:* | *Low Frequency:* | *1 syllable:* | *2 syllable:* |
| p | p | ape | beef | bell | snail | doi (dɔɪ) | chootee (tʃuti) |
| b | b | bird | boot | goat | seal | af (æf) | zhuree (ʒɝi) |
| f | f | bride | bow | pig | comb | toos (tus) | foekoe (foʊkoʊ) |
| v | v | bruise | eel | scale | saddle | sheev (ʃiv) | leber (lɛbɚ) |
| t | t | cave | fig | fork | harp | ek (ɛk) | doem (doʊʌm) |
| d | d | ditch | hay | map | tongs | dach (dætʃ) | mefoe (mɛfoʊ) |
| k | k | fire | thigh | bear | spoon | peenz (pinz) | shever ( ʃɛvɚ) |
| g | g | fur | tire | ghost | ruler | poa (poʊə) | feether (fiðɚ) |
| θ | th | jail | toy | cross | bagpipe | meeth (miθ) | toiler (tɔɪlɚ) |
| ð | th | jeans | whip | deer | anchor | ri (rɪ) | izel (ɑɪzl) |
| s | s | knee | wire | rope | funnel | ish (ɪʃ) | shaybee (ʃeɪbi) |
| z | z | knob | | duck | flashlight | whup (wʌp) | veeder (vidɚ) |
| ʃ | sh | knot | *2 syllable:* | nail | squirrel | breek (brik) | zower (zaʊɚ) |
| ʒ | zh | maze | baby | cane | butterfly | voo (vu) | tawthee (tɑθi) |
| tʃ | ch | mop | iron | pipe | stethoscope | eep (ip) | jiver (dʒɪvɚ) |
| dʒ | j | owl | jury | bat | microscope | reesh (riʃ) | wooter (wutɚ) |
| l | l | pie | ladder | balloon | octopus | nie (nɑɪ) | dungee (dʌŋi) |
| r | r | plane | lasso | ladder | crutches | iej (aɪdʒ) | turmee (tɝmi) |
| h | h | wheel | leather | whistle | pyramid | zine (zɑɪn) | lekzher (lɛkʒɚ) |
| w | w | witch | razor | target | eskimo | broiz (brɔɪz) | lekee (lɛki) |
| wh | wh | | shadow | spider | typewriter | thag (θæg) | juroe (dʒɝo) |
| m | m | *2 syllable:* | turkey | frog | dinosaur | oit (ɔɪt) | shashoe ( ʃæsoʊ) |
| n | n | clover | valet | monkey | binoculars | kur (kɝ) | hoyter (hoɪtɚ) |
| ŋ | ng | diver | | dragon | thermometer | froos (frus) | neenee (nini) |
| i | ee | father | | piano | hippopotamus | grake (greɪk) | rayzel (reɪzl) |
| ɪ | i | genie | | | | choy (tʃɔɪ) | highger (hɑɪgɚ) |
| ɛ | e | gravy | | | | oos (us) | woewuh (woʊwə) |
| eɪ | ae | halo | | | | wap (wæp) | unger (ʌngɚ) |
| æ | a | heater | | | | faps (fæps) | miver (mɑɪvɚ) |
| ʌ, ə | u | ivy | | | | woy (wɔɪ) | jawvee (dʒɑvi) |
| ɑ, ɔ | o, aw | jockey | | | | awch (ɑtʃ) | prezhur (prɛʒɚ) |
| o, oʊ | oe | level | | | | plown (plaʊn) | foover (fuvɚ) |
| ʊ | oo | meadow | | | | zae (zeɪ) | pire (pɑɪɚ) |
| u | oo | movie | | | | hob (hɑb) | dryper (drɑɪpɚ) |
| ɑɪ | ie | polo | | | | veed (vid) | gower (gaʊɚ) |
| ju | ue | ranger | | | | | teever (tivɚ) |
| ɔɪ | oi, oy | shoulder | | | | | ibee (ɑɪbi) |
| aʊ | ow, ou | shower | | | | | |
| ɝ, ɚ | er, ir, ur | speaker | | | | | |
| ɔr | or | teacher | | | | | |
| ɑr | ar | tiger | | | | | |

## Treatment Stimuli and Procedures

Treatment stimuli were created using the same methods as those described in previous studies (Brookshire, Conway, Pompon, Oelke, & Kendall, 2014; Kendall et al., 2015; Kendall et al., under revision) (see Table 2). Stimuli consisted of phonemes in isolation, 39 real words and 69 nonwords. These were phonotactically-legal one and two-syllable words of low phonotactic probability (PP) and high neighborhood density (ND), as determined by methods similar to those outlined in Vitevitch and Luce (1999).

All participants received 56-60 hours of treatment in a massed treatment schedule. Therapy was administered by two licensed and certified speech-language pathologists. Therapy was delivered for a total of 8-10 hours/week over six to seven weeks. Each participant was seen for approximately two hours per day (two 45-50 minute sessions with a 10 minute break between sessions).

The Phonomotor Treatment program has been tested systematically through a number of Phase I (Kendall, Conway, Rosenbeck, & Gonzalez-Rothi, 2003; Raymer, Haley, & Kendall, 2002) and Phase II treatment trials (Kendall, Rodriguez, Rosenbek, Conway, & Rothi, 2006; Kendall et al., 2008; Kendall et al., 2015). The treatment tasks were inspired by the Lindamood Phoneme Sequencing Program (Lindamood & Lindamood, 1998), and created in the context of a parallel distributed processing model of phonology that posits the distribution of phonological knowledge among several representational domains (acoustic, orthographic, and articulatory-motor; Nadeau, 2001). Unlike the IA model that we use to conceptualize naming errors, this PDP model speaks to learning aspects of language processing, and was thus specifically suitable for guiding the treatment approach. The Phonomotor Treatment program consists of two training stages: sounds in isolation and in combination with one another. The first stage focused on multidomain training of individual phonemes, while the second stage focused on phonemes in combination with one another. Treatment tasks were designed to stimulate acoustic, orthographic, and articulatory-motor domains and included training the following skills: articulatory movement awareness (speech motor movements through tasks involving watching their own and the clinician's mouth during productions and selecting mouth pictures for different sounds), production of single phonemes and syllables in a variety of tasks and contexts, acoustic perception (e.g., auditory recognition of the clinician's productions via manipulating blocks corresponding to individual sounds), and grapheme-to-phoneme correspondence. The clinician trained progressively more complex sound combinations (e.g., VC, CV, CVC, CCV, VCC, CCVC, CVCC, CVCV, CCVCC) with each participant as they gained familiarity and proficiency with the treatment tasks. To maintain the treatment's focus on multimodal phonological-level training, nonword stimuli were trained before real word stimuli were introduced. For detailed description of each treatment stage, see Kendall et. al, 2015, Appendix.

## Outcome measures

The outcome measures for all research questions were confrontation picture naming of three sets of stimuli:  1) trained, 2) untrained, linguistically related (U-LR) and 3) untrained, linguistically unrelated (U-LU) stimuli. The trained stimuli consisted of 39 nouns. (see Table 2, *Trained*). The U-LR stimuli consisted of 21 nouns (see Table 2, *Untrained*, *Related*).  Both sets of nouns were comprised of high neighborhood density and low phonotactic probabilities that were calculated using The Irvine Phonotactic Online Dictionary (IPHOD) calculator Version 2.0 (Vaden, Halpin, & Hickok, 2009). A number of linguistic properties were controlled, including frequency, imageability, age of acquisition, syllable number and complexity, and semantic category. Once the word lists were finalized, corresponding non-contextualized, color photographic images were collected to use as stimuli in the naming probes.

In order to test generalization to words that were linguistically unrelated to trained words, a third set of nouns was created. This set of nouns did not include the low phonotactic probability and high neighborhood density characteristics that were used in the treatment stimuli. These stimuli consisted of a subset of 50 nouns from the Philadelphia Naming Test (PNT; Roach et al., 1996) and the Object and Action Naming Battery (O&A; Druks & Masterson, 2000). The chosen subset of nouns was categorized and balanced according to SUBTLEX-US verbal word frequencies (Brysbaert & New, 2009). High- versus low-frequencies were categorized based on a median split (Storkel, Ambruster, & Hogan, 2006). Non-contextualized, color photographic images corresponding to each noun were selected. In the first testing session, all 50 linguistically unrelated noun images were presented randomly on a computer screen to elicit confrontation naming responses. Based on performance in this initial testing session, along with other screening data (e.g., Boston Naming Test performance), more severe participants were assigned to the high-frequency noun condition, and less severe participants were assigned to the low-frequency word list in subsequent sessions (see Table 2, *Untrained, Unrelated*). This assignment was performed in order to tailor stimuli difficulty to each participant’s anomia severity and allow for ample room for improvement.

## Outcome Measure Administration

Outcome measures involving confrontation naming were administered at pre-treatment, immediately post-treatment, and 3 months post-treatment time points. Trained and U-LR stimuli were presented together, and order of items was randomly varied at each time point. U-LU stimuli were presented separately from the other naming stimuli. All picture naming measures were administered using Microsoft Office 2013 Power Point. During the naming tasks, participants wore an Audio-Technica Power Module AT8531 head-mounted microphone connected to a Tascam US-125M USB mixing audio interface. Responses were recorded using Adobe Audition CS6 Version 5.0 software. After three practice trials, participants were asked to name the picture on the screen. Participants were allotted 10 seconds to name each picture. Each trial was followed by a blank white screen for a brief period (2-10 seconds, depending on participant needs) before the next picture was presented.

## Outcome Measure Analysis

All response coding was completed by nine researchers (the authors of this paper) trained on PNT error coding rules by the first author. Responses from the second administration of all three naming probes (T, U-LR, and U-LU) at each time point (pre-treatment, post-treatment, and 3 months post-treatment) were analyzed for whole word accuracy (research question 1) and error type (research questions 2-4). For the first research question, which focused on confrontation picture naming accuracy, participants' responses were transcribed and coded as correct or incorrect. Participants had to produce all sounds correctly in order for a response to count as correct. Sound distortions that did not cross a phonemic boundary were permitted.

For research questions 2-4 (focused on confrontation naming errors), each first complete attempt at naming an item, as defined by the PNT scoring guide (Roach et al., 1996), was coded for accuracy. Incorrect items were then coded for error type using 9 error codes from the PNT error coding system. Consistent with research questions 2-4, we categorized primary error codes into 1) target related errors, which had a clear relationship to the intended word (formal, semantic, mixed, phonologically related nonwords); 2) target unrelated errors (description, unrelated real word, phonologically unrelated nonword, and miscellaneous); and 3) omissions (non-responses, or responses which did not include a first complete attempt, as defined by the PNT). See Table 3 for error coding scheme and examples.

**Table 3.** *Error Coding Scheme (Adapted from the Philadelphia Naming Test)*

| | **Error Type** | **Definition*** | **Examples** (*from present study)* |
|---|---|---|---|
| *Target Related* | | | |
| | Formal | Real word response that is phonologically related to the target | (saddle) → “fiddle”<br>(harp) → “heart” |
| | Semantic | A real word response that is semantically related to the target | (cross) → “church”<br>(duck) → “goose” |
| | Mixed | A real word response that is both phonologically and semantically related to the target | (seal) → “snail”<br>(frog) → “dog” |
| | Phonologically Related Nonword | A nonword response that is phonologically related to the target | (spider) → “/paɪdɚ/”<br>(pipe) → “/paɪpɪ/” |
| *Target Unrelated* | | | |
| | Description | A response that characterizes or attempts to explain the function or purpose of the target. | (harp) → “that sounds like the piano”<br>(thermometer) → “temperature maker” |
| | Unrelated Real Word | A word substitution that is not semantically or phonologically related to the target | (pipe) → “coat”<br>(cane) → “ladder” |
| | Phonologically Unrelated Nonword | A nonword response that is not phonologically related to the target | (spider) →”/vlæk/”<br>(pig) → “/mɑʊ/” |
| | Miscellaneous | A response that is a word blend, morpheme omission, picture part error, proper noun, or phonological jargon | (typewriter) → /type/<br>(pipe) → “/pɑɪ-kə-ki-kə-kək/” |
| *Omission** | Fragment | A minimally CV or VC response that is cut off (schwa not counted) | (nail) → /sæ/-<br>(deer) → /træn/- |
| | No Response | Participant indicates they cannot name the picture, oral spelling, sound effects, or whispered responses | (ghost) → “I know but I don’t”<br>(bell) → “bong bong” |

*Note:* The error type definitions provided are only abbreviations from the Philadelphia Naming Test (PNT) manual. Please see the PNT scoring manual for detailed definitions, scoring rules, and examples (Roach et al., 1996).

*Fragments and No Response errors were combined into one Omission category. Omissions also included incomplete attempts that did not fit the PNT definition of a Fragment (e.g., fork → /s/)

**Data analysis.** To answer research question 1, Wilcoxon signed-rank tests comparing whole word naming accuracy pre-treatment (A1) versus immediately post-treatment (A2) and pre-treatment versus 3 months post-treatment (A3) were performed. All comparisons were performed separately for trained, untrained-linguistically related, and untrained-linguistically unrelated nouns, and alpha level was set at .025 (.05/2) for each of these measures, as each was analyzed at two time points (A1 to A2 and A1 to A3).

For research question 2, target related error proportions (proportion of a given target-related error type divided by the total number of all errors made) were computed for formal, semantic, mixed, and phonologically related nonwords. Wilcoxon signed-rank tests comparing proportions within a particular error type were performed pre-treatment versus immediately post-treatment and pre-treatment versus 3 months post-treatment. The same procedures were followed for the target-unrelated errors (description, unrelated real word, phonologically unrelated nonword, and miscellaneous) and for omission errors (research questions 3 and 4, respectively), and all comparisons were performed separately for trained, untrained-linguistically related, and untrained-linguistically unrelated nouns. Alpha level was determined per stimulus type (trained, U-LR, and U-LU), and time point (pre-treatment to post-treatment and pre-treatment to 3 months post-treatment). For example, for trained words compared pre-treatment to post-treatment, alpha level was set at .0125 (.05/4) because four separate comparisons, one for each related error type, were made. These same procedures were followed for unrelated errors, as there were also four subtypes of unrelated errors. Because research question 4 dealt with only one error category (omission errors), alpha level determination procedures mirrored those of research question 1: alpha level was set at .025 (.05/2).

To assess intra-rater and inter-rater reliability, 10% of each linguistically related (trained and U-LR) and linguistically unrelated (U-LU) lists were transcribed and coded by the same rater and by a different rater, respectively. Cohen's kappa coefficients (Landis & Koch, 1977) were calculated for both measures.

# Results

## Reliability of Outcome Measure Scoring

The intra-rater reliability analysis demonstrated substantial agreement on both trained/linguistically related ($\kappa$ = .804) and linguistically unrelated ($\kappa$ = .753) stimuli. Similarly, the inter-rater reliability analysis also demonstrated substantial agreement on both trained/linguistically related ($\kappa$ = .710) and linguistically unrelated ($\kappa$ = .637) stimuli.

## Research Question 1: Naming Accuracy

Individual, mean, and median trained and untrained naming accuracy proportions for each time point are listed in Appendix A. Results of Wilcoxon signed-rank tests comparing naming accuracy on trained items showed a statistically significant improvement in naming accuracy (*Mdn increase* = .167) when comparing pre-treatment (*Mdn* = .333) and immediate post-treatment probes (*Mdn* = .551), *Z* = -4.501, p < .001, as well as when comparing pre-treatment and 3 months maintenance probes (*Mdn* = .500; *Mdn* increase = .102), *Z* = -4.311, p < .001. Results of Wilcoxon signed-rank tests comparing naming accuracy on U-LR items did not show a significant improvement in naming accuracy when comparing pre-treatment and immediate post-treatment probes, *Z* = -1.576, *p* = .115; however, a significant improvement in naming accuracy (*Mdn* increase = .048) was found when comparing pre-treatment (*Mdn* = 0.405) and 3 months post-treatment probes (*Mdn* = 0.429), *Z* = -2.498, *p* = .012. Results of Wilcoxon signed-rank tests comparing naming accuracy on U-LU items did not show a significant improvement immediately post-treatment, $Z = -.903$, $p = .366$, or 3 months following treatment completion, $Z = -1.26$, $p = .208$. See Table 4 for full results.

**Table 4.** *Whole Word Accuracy Wilcoxon Signed-Rank Test Results (Research Question 1)*

| **Noun Condition** | **Contrast** | ***Z*** | **Alpha** $^{+}$ | ***p*** |
|---|---|---|---|---|
| Trained | Pre – imm. post | -4.501 | .025 | <.001***** |
| | Pre-3 months post | -4.311 | .025 | <.001***** |
| Untrained, Linguistically Related | Pre – imm. post | -1.576 | .025 | 0.115 |
| | Pre-3 months post | -2.498 | .025 | 0.012***** |
| Untrained, Linguistically Unrelated | Pre – imm. Post | -0.903 | .025 | 0.366 |
| | Pre-3 months post | -1.26 | .025 | 0.208 |

*Note*: Significant *p* values are starred.

## Research Question 2: Changes in target related errors

Individual, mean, and median trained and untrained naming error proportions (derived by dividing raw numbers of each error type by total number of errors) for each error type at each time point are listed in Appendices B1-B3. No significant results emerged for any of the four error types (formal, semantic, nonword, or mixed) in any of the three stimuli conditions (trained items, U-LR items, or U-LU items). None of the contrasts were significant at either time point (pre- versus immediately post-treatment and pre- versus 3 months post-treatment). See Table 5 for full results.

**Table 5.** *Related Error Proportion Wilcoxon Signed-Rank Test Results (Research Question 2)*

| Noun Condition | Error Type | Contrast | *Z* | Alpha $^{+}$ | *p* |
|---|---|---|---|---|---|
| Trained | Formal | Pre – imm. post | -0.438 | 0.0125 | 0.661 |
| | | Pre-3 months post | -0.198 | 0.0125 | 0.843 |
| | Semantic | Pre – imm. post | -0.82 | 0.0125 | 0.412 |
| | | Pre-3 months post | -0.288 | 0.0125 | 0.773 |
| | Nonword | Pre – imm. post | -0.925 | 0.0125 | 0.355 |
| | | Pre-3 months post | -1.40 | 0.0125 | 0.162 |
| | Mixed | Pre – imm. post | -1.568 | 0.0125 | 0.117 |
| | | Pre-3 months post | -1.018 | 0.0125 | 0.309 |
| Untrained, Linguistically Related | Formal | Pre – imm. post | -1.008 | 0.0125 | 0.313 |
| | | Pre-3 months post | -0.869 | 0.0125 | 0.385 |
| | Semantic | Pre – imm. post | -0.978 | 0.0125 | 0.328 |
| | | Pre-3 months post | -0.536 | 0.0125 | 0.592 |
| | Nonword | Pre – imm. post | -0.327 | 0.0125 | 0.744 |
| | | Pre-3 months post | -0.852 | 0.0125 | 0.394 |
| | Mixed | Pre – imm. post | -1.425 | 0.0125 | 0.154 |
| | | Pre-3 months post | -0.533 | 0.0125 | 0.594 |
| Untrained, Linguistically Unrelated | Formal | Pre – imm. post | -0.438 | 0.0125 | 0.661 |
| | | Pre-3 months post | -0.198 | 0.0125 | 0.843 |
| | Semantic | Pre – imm. post | -0.82 | 0.0125 | 0.412 |
| | | Pre-3 months post | -0.288 | 0.0125 | 0.773 |
| | Nonword | Pre – imm. post | -0.925 | 0.0125 | 0.355 |
| | | Pre-3 months post | -1.4 | 0.0125 | 0.162 |
| | Mixed | Pre – imm. post | -1.568 | 0.0125 | 0.117 |
| | | Pre-3 months post | -1.018 | 0.0125 | 0.309 |

*Note*: No significant contrasts emerged for related error proportions.

### Research Question 3: Changes in target unrelated errors

Individual, mean, and median trained and untrained naming error proportions (derived by dividing raw numbers of each error type by total number of errors) for each error type at each time point are listed in Appendices C1-C3. When unrelated errors (descriptions, neologisms, unrelated, and miscellaneous errors) were examined, there were several notable observations for description errors. There was a statistically significant decrease (*Mdn decrease* = .028) in proportion of description errors on trained items when comparing pre-treatment (*Mdn* = .074) to immediate post-treatment (*Mdn* = .037) error proportions, *Z* = -2.552, *p* =.011, and a trend towards a significant decrease (*Mdn decrease = .036*) in proportion of description errors on trained items when comparing pre-treatment (*Mdn* = .074) to 3 months post-treatment (*Mdn* = .053) error proportions, *Z* = -2.286, *p* = .022. No other significant contrasts emerged when comparing target-unrelated error proportions on trained items pre to post-treatment or pre to 3 months post-treatment.

No significant contrasts or notable trends emerged for U-LR items for any target-unrelated error type at any time point. For U-LU items, trends emerged when comparing proportions of description errors pre- to immediately post-treatment, *Z* = -2.417, *p* = .016, and pre- to 3 months post-treatment, *Z* = -2.119, *p* = .034. Though both the median proportions and median proportion decreases for all time points were 0, the mean proportions of description errors decreased from .065 to .020 immediately post-treatment and from .065 to .031 3 months post-treatment. No other significant contrasts emerged when comparing U-LU error proportions on untrained linguistically unrelated items pre to post-treatment or pre to 3 months post-treatment. See Table 6 for full results.

**Table 6.** *Unrelated Error Proportion Wilcoxon Signed-Rank Test Results (Research Question 3)*

| **Noun Condition** | **Error Type** | **Contrast** | ***Z*** | **Alpha** $^{+}$ | ***p*** |
|---|---|---|---|---|---|
| Trained | Description | Pre – imm. post | -2.552 | 0.0125 | **0.011*** |
| | | Pre-3 months post | -2.286 | 0.0125 | 0.022~ |
| | Neologism | Pre – imm. post | -1.089 | 0.0125 | 0.276 |
| | | Pre-3 months post | -0.24 | 0.0125 | 0.811 |
| | Unrelated | Pre – imm. post | -1.241 | 0.0125 | 0.214 |
| | | Pre-3 months post | -1.045 | 0.0125 | 0.296 |
| | Miscellaneous | Pre – imm. post | -0.445 | 0.0125 | 0.656 |
| | | Pre-3 months post | -1.175 | 0.0125 | 0.24 |
| Untrained, Linguistically Related | Description | Pre – imm. post | -1.268 | 0.0125 | 0.205 |
| | | Pre-3 months post | -0.4 | 0.0125 | 0.689 |
| | Neologism | Pre – imm. post | -0.199 | 0.0125 | 0.842 |
| | | Pre-3 months post | -0.235 | 0.0125 | 0.814 |
| | Unrelated | Pre – imm. post | -0.284 | 0.0125 | 0.776 |
| | | Pre-3 months post | -0.629 | 0.0125 | 0.529 |
| | Miscellaneous | Pre – imm. post | -1.153 | 0.0125 | 0.249 |
| | | Pre-3 months post | -1.367 | 0.0125 | 0.172 |
| Untrained, Linguistically Unrelated | Description | Pre – imm. post | -2.417 | 0.0125 | 0.016~ |
| | | Pre-3 months post | -2.119 | 0.0125 | 0.034~ |
| | Neologism | Pre – imm. post | -0.284 | 0.0125 | 0.776 |
| | | Pre-3 months post | -0.776 | 0.0125 | 0.438 |
| | Unrelated | Pre – imm. post | -0.114 | 0.0125 | 0.91 |
| | | Pre-3 months post | -1.676 | 0.0125 | 0.094 |
| | Miscellaneous | Pre – imm. post | -1.521 | 0.0125 | 0.128 |
| | | Pre-3 months post | -1.29 | 0.0125 | 0.197 |

*Note*: Significant *p* values are bolded and starred. Trends are denoted with a ~ symbol.

### ***Research Question 4: Changes in omission errors***

Individual, mean, and median trained and untrained omission error proportions (derived by dividing raw numbers of omission errors by total number of naming errors) at each time point are listed in Appendix D. For trained items, a statistically significant decrease (*Mdn decrease* = .083) in proportion of omission errors was found when comparing pre-treatment (*Mdn* = .194) to immediate post-treatment (*Mdn* = .071) error proportions, *Z* = -3.086, *p* =.002. Additionally, there was a trend towards a significant decrease (*Mdn decrease* = .075) in proportion of omission errors when comparing pre-treatment (*Mdn* = .194) to 3 months post-treatment (*Mdn* = .089) error proportions, *Z* = -2.086, *p* = .037.

A trend towards a significant decrease (*Mdn decrease* = .053) for U-LU items emerged when comparing proportions of omission errors pre-treatment (*Mdn* = .251) to 3 months post-treatment (*Mdn* = 0.179), *Z* = 0.435, *p* = .065. No other contrasts of note emerged for untrained items of any kind. See Table 7 for full results.

**Table 7.** *Omission Proportion Wilcoxon Signed-Rank Test Results (Research Question 4)*

| **Noun Condition** | **Contrast** | ***Z*** | **Alpha** $^{+}$ | ***p*** |
|---|---|---|---|---|
| Trained | Pre – imm. post | -3.086 | .025 | **0.002*** |
| | Pre-3 months post | -2.086 | .025 | 0.037~ |
| Untrained, Linguistically Related | Pre – imm. post | -0.837 | .025 | 0.403 |
| | Pre-3 months post | -0.24 | .025 | 0.811 |
| Untrained, Linguistically Unrelated | Pre – imm. Post | -0.78 | .025 | 0.435 |
| | Pre-3 months post | 0.435 | .025 | 0.065~ |

*Note*: Significant *p* values are bolded and starred. Trends are denoted with a ~ symbol.

Overall, two significant error proportion results emerged when comparing pre-treatment and immediate post-treatment time points: A decrease in proportions of description and omission errors, in the context of significantly improved whole word naming accuracy. The decrease in omission error proportions is consistent with findings from our previous studies (Kendall et al., 2013; Minkina et al., 2016) and will be discussed in context of these previous findings in the discussion section. The decrease in proportion of description errors is a less expected result deserving of further exploration. In the PNT coding system, the description error category is very broad, encompassing a variety of responses. Thus, a post-hoc analysis was conducted to determine whether a particular type of description error drove this result (Post hoc 1). Additionally, though we did not find any significant treatment-induced shifts in target-related errors, we were curious whether there were any differences in target-related errors in less severely versus more severely anomic individuals that may have been concealed in the full group analysis (Post hoc 2). Methodology and results for both post hoc analyses are discussed below.

### Post hoc 1: A closer look at changes in description errors

The main results revealed a significant decrease in the proportion of description errors for trained items immediately post-treatment, a trend towards a decrease in proportion of description errors for trained items 3 months post-treatment, and trends at both post-treatment timepoints for U-LU items. Because descriptions encompass such a broad category on the PNT, a closer look at these results was warranted. The first author retroactively categorized all description errors into one of seven categories (listed in Table 8). Two of these error types (D1 and D6) were classified as semantic descriptions, one was an unrelated description (D2), and three were classified as embedded target descriptions (D3, D4, and D5). The remaining code (D7) was reserved for errors that the first author deemed to be incorrectly coded by other raters as descriptions. Though overall error coding reliability was high, error coding is a challenging endeavor, so the need for such a category to encompass the small number of incorrectly coded descriptions errors was expected. Error proportions for each description subtype were calculated by dividing raw numbers of that error subtype by the raw number of all description errors for each participant at each time point. Alpha level depended on the error subtype in question. For example, when analyzing shifts in subtypes of semantic descriptions for trained nouns pre to immediately post-treatment, alpha level was .05/2 (.025) because there were two errors of this subtype (D1 and D6).

**Table 8**. *Description Error Subtypes for Post hoc Analysis 1*

| **Description Error Subtype** | **Code** | **Example** |
|---|---|---|
| A single verb, adjective, or adverb that has a semantic relationship to the target | D1 | (speaker) → "speaking" |
| A single verb, adjective or adverb that has no relationship to the target | D2 | (tiger) → "new" |
| A response in the form "type of X" where "X" is a superordinate of the target | D3 | *Not observed* |
| A response that negates the target (not a X) | D4 | *Not observed* |
| A response that includes a carrier phrase with the name of the target (open the door) | D5 | (knee) → "breaking knee" |
| A response that attempts to explain the target's function or purpose | D6 | (meadow) → "beautiful woods" |
| Description coded incorrectly | D7 | ▨ |

All description error subtype proportions on trained nouns and U-LU nouns were compared with Wilcoxon signed-rank tests pre- to immediately post-treatment and pre to 3 months post-treatment. A trend emerged for D1 type errors, defined as single verbs, adjectives, or adverbs that had a semantic relationship to the target. D1 errors trended towards a decrease (*Mdn decrease* = 0) when comparing performance on trained nouns pre-treatment (*Mdn.*= 0.174; *Mean* = 0.34) to immediately post-treatment (*Mdn* = 0; *Mean* = 0.17), *Z* = -1.900, *p* = .057, and when comparing performance on trained nouns pre-treatment to 3 months post-treatment (*Mdn = 0; Mdn decrease =0; Mean* = 0.150), *Z* = -1.93, *p* = .054. Additionally, D1 errors trended towards a decrease (*Mdn decrease* = 0) when comparing performance on untrained, linguistically unrelated nouns pre-treatment (*Mdn* = 0; *Mean* = .108) to 3 months post-treatment (*Mdn* = 0; *Mean* = .070), *Z* = -2.032, *p* = .042. No significant contrasts emerged.

## Post hoc 2: Target-related errors in less versus more severely anomic individuals

All Wilcoxon signed-rank comparisons performed for research question 2 were repeated for two subgroups of individuals: High lexical retrieval (milder individuals, who received the low frequency U-LU word list) and low lexical retrieval (more severe individuals, who received the high frequency U-LU word list), based on category membership determined at study enrollment. The same procedures for determining significant contrasts were followed for each group as were followed for the full group of participants. One contrast of note emerged for the low (more severe) lexical retrieval individuals. There was a trend towards an increase (*Mdn increase* = .038) in mixed errors on trained nouns pre-treatment (*Mdn* = 0) to post-treatment for the group of individuals with lower lexical retrieval ability (*Mdn* = .04), *Z* = -2.497, *p* = .013, which will be addressed in the context of a previous similar observation (Kendall et al., 2013) in the discussion section.

# Discussion

The purpose of this study was to extend previous studies that investigated changes in anomic errors following Phonomotor Treatment (Kendall et al., 2013; Minkina et al., 2016). The present study used a more comprehensive coding scheme than that of our previous work to investigate word retrieval errors in our largest sample to date. We first discuss implications of the whole word accuracy findings (research question 1), and then, discuss results of our error analysis (examinations of related, unrelated, and omission error proportions, research questions 2-4). We also embed a discussion of several post-hoc analyses that further elucidate the evolution of target related and description errors following Phonomotor Treatment.

## Research Question 1: Naming Accuracy

Our findings for trained noun naming were consistent with previous findings (Kendall et al., 2013, Kendall et al., 2015; Minkina et al., 2016): trained nouns improved, and this improvement was maintained at the 3 months post-treatment testing phase. These results demonstrated the efficacy of an intensive, multimodal phoneme-based approach in improving whole word accuracy, and more importantly, creating lasting word retrieval changes. To fully understand the potency of this approach, it is important to emphasize that the trained nouns were treated only through the phonologically based tasks described above (see *Treatment Stimuli and Procedures*). Participants never saw corresponding pictures during the treatment itself. Furthermore, semantic features and word meanings were never discussed during treatment. While auditory word processing necessarily activates both lexical-semantic and phonological knowledge, treatment facilitated direct stimulation of phonological knowledge only. Additionally, nonword training accounted for the majority of treatment hours, while real word training was not typically introduced until the last 20 training hours. Together, these aspects of the treatment paradigm suggest that phonological training was the primary mechanism through which participants improved and maintained improvements in word retrieval.

The improvement in untrained, linguistically related items 3 months post-treatment is consistent with previous results (Kendall et al., 2015; Minkina et al., 2016), and further speaks to the potency of a phoneme-based treatment approach. According to the theoretical underpinnings of Phonomotor Treatment, which is based on a parallel distributed model of phonology (Nadeau, 2001), distributed training of sounds and sound sequences should holistically stimulate phonological knowledge that subserves all lexical items. Thus, Phonomotor Treatment should promote generalization to untrained lexical items. Because fundamental building blocks of all words are the focus of therapy, rather than a small subset of real words (as is the case with most semantic-based naming therapies), practice through language use in natural settings after participants complete Phonomotor Treatment should lead to continued improvements in word retrieval after treatment completion. This may explain why U-LR did not improve immediately following treatment, but improved significantly following a 3 month gap. Though participants demonstrated generalization to U-LR nouns at the maintenance time point, no significant changes emerged for U-LU nouns. There are several possible explanations for this result. First, it is possible that Phonomotor Treatment, at least at the current dosage, is not potent enough to lead to measurable whole word improvements on phonologically unrelated items (i.e., items that were *not* matched with trained items on phonotactic probability or neighborhood density). Second, it is possible that a larger number of testing items are needed to adequately measure such changes (only 25 items were used in the present study). Future Phonomotor Treatment studies that include a larger number of untrained, phonologically unrelated stimuli will be able to elucidate whether there is more to the story beyond our current findings.

## Research Question 2: Related Errors

We examined proportions of four types of related errors (formal, semantic, nonword, and mixed) prior to, immediately post, and 3 months post-treatment. According to Dell et al. (1997), errors with a clear semantic or phonological relationship to the target indicate a certain level of integrity in the connections among semantic, lexical, and phonological nodes in the word retrieval network; however, the nodes' activation decays too quickly, allowing for phonological and semantic neighbors to be selected instead of the target item. We did not see any significant changes for related errors, for any measure, at either post-treatment time point. This result is consistent with our previous findings (Minkina et al., 2016), where we did not see significant changes in semantic or phonological errors after Phonomotor Treatment. These findings are consistent with Dell's Interactive Activation model of word retrieval. Dell et al. (1997) posit two stages of word retrieval: 1) word form (lemma) selection, in which semantic nodes are activated, and the word form most consistent with the activated nodes is selected, and 2) phonological selection, in which sounds consistent with the chosen lemma are selected. While two distinct stages are identified, they do not occur in isolation: before a lemma is selected, sounds associated with highly activated lemmas provide feedback activation to higher levels (lemma and semantic) of processing. Therefore, phonological nodes exert a strong influence on the lexical-semantic network. Thus, intensive phoneme-based training should influence not only phonological-level nodes, but also affect the entire word retrieval network. In that case, differential changes in specific related errors would not be expected, as phoneme-based training should exert a strong influence on both phonological and semantic nodes.

Still, we elected to take a closer look at related errors, performing the same analysis but separating out higher severity (lower lexical retrieval) individuals and lower severity (higher lexical retrieval) individuals. Minkina et al. (2016) signaled the importance of examining subgroups of more severe versus less severe individuals when they demonstrated a significant decrease in omission errors in individuals with lower lexical retrieval ability only, while only a trend was found in the full group of participants. In the current study, when we conducted a post-hoc analysis with two subgroups separated on the basis of their pre-treatment lexical retrieval ability, we found a trend towards an *increase* in mixed errors on trained items immediately post-treatment for the group with lower lexical retrieval ability. Though trends should always be interpreted with caution, this finding is interesting for several reasons. First, Kendall et al. (2013) also observed a trend towards an increase in mixed errors immediately post-treatment, and though it was for linguistically related, *untrained* items in our previous work, the fact that mixed errors tended to shift upwards in both our previous and current investigations should be considered. Theoretically, the upward shift in mixed errors is consistent with the prediction that, based on the influence of phonological-level nodes on lexical-semantic activation (Dell et al., 1997), Phonomotor Treatment should exert a holistic influence on the word retrieval network. Because mixed errors are both phonologically and semantically related to the target, their increase indicates increased interactivity among phonological and semantic nodes, which is consistent with the predicted influence of Phonomotor Treatment on both phonological and semantic nodes.

## Research Question 3: Unrelated Errors

Perhaps the most surprising result of the study was the statistically significant decrease in the proportion of description errors on trained items immediately post-treatment. This result was coupled with trends toward the same pattern for trained words 3 months post-treatment, as well as U-LU words immediately post- and 3 months post-treatment. Because description errors encompassed such a broad category in the PNT coding scheme (Table 8 lists the possible subtypes of description errors), we conducted a post-hoc analysis on trained and untrained, linguistically unrelated words at both post-treatment time points (immediate and 3 months maintenance) to determine whether a specific type of description error was driving these results. When comparing numbers of specific subtypes of description errors relative to all description errors made, only D1 type descriptions (single verbs, adjectives, or adverbs that had a semantic relationship to the target) tended to decrease following treatment. Though only trends emerged, these observations bring up an error categorization question: Is it meaningful to separate semantic errors of nouns from semantic errors of other word classes? Perhaps the observed trends suggest that, following treatment, participants were better able to overcome interference from semantically related lexical items that were not nouns, suggesting more precise lexical activation; however, we must also note that participants were not given explicit instructions to provide noun responses, though the pictures were heavily biased towards such responses. Perhaps one conclusion we can make from these trends is that it may be important to cue participants to produce noun responses only in order to help decrease semantic interference from other word classes.

## Research Question 4: Omission Errors

Our results with omission errors are similar, but not identical, to our earlier findings (Minkina et al., 2016). Our current results demonstrated a significantly reduced proportion of omission errors on trained items, as well as trends towards a reduction in the proportion of omission errors on trained items 3 months post-treatment and on untrained, *linguistically unrelated* items 3 months post-treatment. Our prior results demonstrated trends towards decreases in proportions of omission errors on trained items immediately and 3 months post treatment, as well as a trend towards the same pattern on untrained, *linguistically related* items 3 months post-treatment. To interpret these results, we must consider what omissions can and cannot tell us about an individuals' word retrieval impairment. Because an omissions error is, by definition, the absence of a concrete response, this error type is ambiguous. It is not possible to know the process that caused an omission error to occur. For example, one participant may produce omission errors because they are self-monitoring alternative, more meaningful responses that are activated but ultimately inhibited because the participant knows they are not correct. On the other end of the spectrum, another participant may not be able to activate semantic nodes to a sufficient threshold needed to initiate word retrieval. The latter explanation is consistent with Dell's model of omission errors (Dell, Lawler, Harris, & Gordon, 2004), which posits that insufficient conceptual-semantic activation does not allow the initiation of lemma selection. Similarly, a recent interdisciplinary study by Chen, Middleton, & Mirman (2018) demonstrated both a neural and computational connection between omission errors and lexical-semantic word retrieval impairments. Importantly, omission errors have also been attributed to phonological impairment: Halai, Woollams, and Ralph (2018) recently conducted a principal components analysis that demonstrated that omission errors loaded on semantic working memory *and* phonological working memory factors, a result that is consistent with the ambiguous nature of omission errors.

Our results, in the context of these recent studies, suggest that Phonomotor Treatment holistically impacted the word retrieval network. The decrease in omission errors on trained items immediately post-treatment is consistent with the results of target related errors, in that they also indicate a global shift in the word retrieval network. Theoretically, these findings provide additional evidence that phoneme-based training can increase activation of higher-level (i.e., lexical-semantic) nodes. Additionally, though the decreases in omission errors for untrained, linguistically unrelated items are trends and should be interpreted with caution, they suggest the importance of more fine-grained measures coupled with accuracy measures, as no notable observations emerged when comparing whole word accuracy on these items pre- to post-treatment or pre- to 3 months post-treatment.

## Conclusions

The results of this study speak to the potential of error analyses to elucidate treatment effects beyond what is possible with solely accuracy-based measures. Unlike whole word accuracy measures, error analyses can speak to changes at different levels of processing (e.g., semantic, lexical, phonological), and can serve as more sensitive measures of change in the absence of shifts in whole word accuracy. In addition to improvements in whole word accuracy observed for both trained and untrained targets, our analysis suggests that Phonomotor Treatment influenced the word retrieval network in a global manner, affecting lexical-semantic as well as phonological knowledge. These results are consistent with the linguistically distributed treatment tasks used in Phonomotor Treatment, and speak to the ability of this treatment to exert a global influence on the word retrieval network. Whether semantic-based treatment at the same intensity and dosage would yield similar or different shifts in word retrieval errors remain to be seen. We are currently investigating this topic. Though these types of investigations are still few in number, they are growing rapidly, and an influx of interest in treatment-induced changes in word retrieval errors will lead to a deeper and more complete understanding of the processing mechanisms underlying acquisition and generalization of linguistic knowledge following anomia treatment.

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# Supplementary Material

**Appendix A.** *Accuracy Proportions for Trained, Untrained-Related, and Untrained-Unrelated Nouns*

| | **Trained Nouns** | | | **Untrained Nouns, Related** | | | **Untrained Nouns, Unrelated** | | |
|---|---|---|---|---|---|---|---|---|---|
| **ID** | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos |
| PM01PDX | 0.72 | 0.90 | 0.77 | 0.81 | 0.81 | 0.76 | 0.96 | 0.84 | 0.96 |
| PM01SEA | 0.59 | 0.82 | 0.67 | 0.62 | 0.71 | 0.52 | 0.44 | 0.32 | 0.36 |
| PM02PDX | 0.44 | 0.56 | 0.72 | 0.57 | 0.71 | 0.67 | 0.8 | 0.8 | 0.76 |
| PM02SEA | 0.72 | 0.95 | 0.87 | 0.86 | 0.76 | 0.86 | 0.8 | 0.76 | 0.72 |
| PM03SEA | 0.03 | 0.18 | 0.15 | 0.05 | 0.05 | 0.05 | 0.12 | 0.16 | 0.08 |
| PM04PDX | 0.21 | 0.33 | 0.36 | 0.24 | 0.38 | 0.43 | 0.32 | 0.4 | 0.48 |
| PM04SEA | 0.23 | 0.18 | 0.28 | 0.19 | 0.24 | 0.38 | 0.28 | 0.24 | 0.20 |
| PM05PDX | 0.67 | 0.64 | 0.74 | 0.71 | 0.76 | 0.71 | 0.64 | 0.52 | 0.68 |
| PM05SEA | 0.10 | 0.36 | 0.21 | 0.05 | 0.14 | 0.05 | 0.16 | 0.28 | 0.24 |
| PM06PDX | 0.08 | 0.10 | 0.08 | 0.05 | 0.10 | 0.10 | 0.24 | 0.36 | 0.32 |
| PM06SEA | 0.33 | 0.46 | 0.44 | 0.24 | 0.29 | 0.38 | 0.32 | 0.48 | 0.28 |
| PM07PDX | 0.49 | 0.82 | 0.69 | 0.57 | 0.43 | 0.62 | 0.36 | 0.4 | 0.56 |
| PM07SEA | 0.21 | 0.36 | 0.23 | 0.38 | 0.29 | 0.24 | 0.24 | 0.28 | 0.28 |
| PM08PDX | 0.00 | 0.03 | 0.03 | 0.00 | 0.05 | 0.05 | 0.00 | 0.00 | 0.00 |
| PM08SEA | 0.77 | 1.00 | 0.90 | 0.76 | 0.90 | 0.95 | 0.52 | 0.68 | 0.68 |
| PM09PDX | 0.41 | 0.69 | 0.74 | 0.71 | 0.76 | 0.86 | 0.32 | 0.60 | 0.92 |
| PM09SEA | 0.46 | 0.79 | 0.72 | 0.48 | 0.43 | 0.52 | 0.48 | 0.32 | 0.56 |
| PM10PDX | 0.15 | 0.36 | 0.21 | 0.19 | 0.33 | 0.33 | 0.4 | 0.52 | 0.52 |
| PM11PDX | 0.31 | 0.54 | 0.41 | 0.38 | 0.24 | 0.33 | 0.56 | 0.64 | 0.56 |
| PM11SEA | 0.15 | 0.23 | 0.13 | 0.19 | 0.10 | 0.24 | 0.16 | 0.24 | 0.12 |
| PM12PDX | 0.00 | 0.13 | 0.05 | 0.10 | 0.10 | 0.10 | 0.08 | 0.08 | 0.04 |
| PM12SEA | 0.64 | 0.77 | 0.79 | 0.81 | 0.86 | 0.81 | 0.44 | 0.20 | 0.32 |
| PM13SEA | 0.13 | 0.26 | 0.13 | 0.05 | 0.14 | 0.14 | 0.36 | 0.12 | 0.16 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| PM14SEA | 0.33 | 0.85 | 0.74 | 0.43 | 0.62 | 0.81 | 0.76 | 0.84 | 0.84 |
| PM15SEA | 0.56 | 0.79 | 0.56 | 0.67 | 0.48 | 0.43 | 0.56 | 0.68 | 0.44 |
| PM16SEA | 0.67 | 0.90 | 0.85 | 0.52 | 0.71 | 0.71 | 0.72 | 0.72 | 0.76 |
| PM17SEA | 0.56 | 0.90 | 0.85 | 0.57 | 0.71 | 0.86 | 0.8 | 0.8 | 0.96 |
| PM18SEA | 0.23 | 0.36 | 0.26 | 0.10 | 0.14 | 0.24 | 0.16 | 0.28 | 0.32 |
| ***M*** | 0.36 | 0.54 | 0.48 | 0.40 | 0.44 | 0.47 | 0.43 | 0.45 | 0.47 |
| ***SD*** | 0.24 | 0.30 | 0.30 | 0.28 | 0.29 | 0.29 | 0.25 | 0.25 | 0.29 |
| ***Mdn*** | 0.33 | 0.55 | 0.50 | 0.40 | 0.40 | 0.43 | 0.38 | 0.40 | 0.46 |

*M* = mean; *SD* = standard deviation; *Mdn* = median

**Appendix B1.** *Target Related Error Proportions for Trained Nouns*

| | **Formal** | | | **Semantic** | | | **Mixed** | | | **Phonologically Related Nonword** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ID** | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos |
| PM01PDX | 0.00 | 0.00 | 0.00 | 0.36 | 1.00 | 0.78 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM01SEA | 0.13 | 0.00 | 0.00 | 0.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.50 | 1.00 | 0.92 |
| PM02PDX | 0.05 | 0.06 | 0.00 | 0.27 | 0.59 | 0.55 | 0.00 | 0.12 | 0.00 | 0.05 | 0.00 | 0.00 |
| PM02SEA | 0.00 | 0.00 | 0.00 | 0.45 | 0.50 | 0.40 | 0.36 | 0.00 | 0.60 | 0.00 | 0.00 | 0.00 |
| PM03SEA | 0.00 | 0.00 | 0.00 | 0.13 | 0.09 | 0.18 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.03 |
| PM04PDX | 0.06 | 0.50 | 0.12 | 0.06 | 0.12 | 0.04 | 0.00 | 0.04 | 0.08 | 0.26 | 0.00 | 0.40 |
| PM04SEA | 0.07 | 0.09 | 0.00 | 0.03 | 0.03 | 0.00 | 0.03 | 0.03 | 0.00 | 0.20 | 0.34 | 0.21 |
| PM05PDX | 0.15 | 0.07 | 0.10 | 0.23 | 0.29 | 0.20 | 0.23 | 0.21 | 0.00 | 0.08 | 0.07 | 0.00 |
| PM05SEA | 0.09 | 0.00 | 0.06 | 0.00 | 0.08 | 0.00 | 0.00 | 0.12 | 0.00 | 0.34 | 0.08 | 0.74 |
| PM06PDX | 0.08 | 0.09 | 0.03 | 0.22 | 0.20 | 0.19 | 0.00 | 0.00 | 0.14 | 0.00 | 0.14 | 0.06 |
| PM06SEA | 0.08 | 0.05 | 0.05 | 0.19 | 0.19 | 0.27 | 0.04 | 0.10 | 0.00 | 0.04 | 0.10 | 0.00 |
| PM07PDX | 0.00 | 0.14 | 0.00 | 0.35 | 0.71 | 0.25 | 0.00 | 0.00 | 0.25 | 0.10 | 0.14 | 0.08 |
| PM07SEA | 0.03 | 0.00 | 0.03 | 0.19 | 0.32 | 0.20 | 0.06 | 0.04 | 0.00 | 0.03 | 0.00 | 0.00 |
| PM08PDX | 0.03 | 0.03 | 0.03 | 0.00 | 0.03 | 0.03 | 0.00 | 0.00 | 0.03 | 0.08 | 0.24 | 0.13 |
| PM08SEA | 0.11 | 0.00 | 0.00 | 0.33 | 0.00 | 0.25 | 0.11 | 0.00 | 0.50 | 0.22 | 0.00 | 0.25 |
| PM09PDX | 0.39 | 0.08 | 0.00 | 0.48 | 0.42 | 0.90 | 0.00 | 0.08 | 0.00 | 0.04 | 0.25 | 0.00 |
| PM09SEA | 0.00 | 0.00 | 0.09 | 0.33 | 0.63 | 0.64 | 0.14 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM10PDX | 0.15 | 0.20 | 0.26 | 0.15 | 0.04 | 0.06 | 0.00 | 0.04 | 0.03 | 0.42 | 0.56 | 0.42 |
| PM11PDX | 0.00 | 0.00 | 0.04 | 0.37 | 0.33 | 0.61 | 0.00 | 0.22 | 0.00 | 0.07 | 0.06 | 0.09 |
| PM11SEA | 0.06 | 0.10 | 0.03 | 0.12 | 0.13 | 0.21 | 0.00 | 0.00 | 0.00 | 0.09 | 0.13 | 0.00 |
| PM12PDX | 0.00 | 0.15 | 0.03 | 0.05 | 0.12 | 0.05 | 0.00 | 0.00 | 0.03 | 0.03 | 0.00 | 0.05 |
| PM12SEA | 0.14 | 0.22 | 0.38 | 0.14 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.36 | 0.78 | 0.63 |
| PM13SEA | 0.03 | 0.00 | 0.00 | 0.06 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 |
| PM14SEA | 0.23 | 0.33 | 0.30 | 0.12 | 0.17 | 0.00 | 0.00 | 0.17 | 0.00 | 0.23 | 0.17 | 0.30 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PM15SEA | 0.00 | 0.25 | 0.06 | 0.29 | 0.25 | 0.18 | 0.00 | 0.13 | 0.00 | 0.06 | 0.00 | 0.18 |
| PM16SEA | 0.00 | 0.00 | 0.00 | 0.62 | 0.75 | 0.67 | 0.00 | 0.00 | 0.17 | 0.23 | 0.25 | 0.00 |
| PM17SEA | 0.06 | 0.00 | 0.00 | 0.47 | 0.50 | 0.33 | 0.00 | 0.50 | 0.67 | 0.00 | 0.00 | 0.00 |
| PM18SEA | 0.03 | 0.04 | 0.14 | 0.23 | 0.16 | 0.10 | 0.00 | 0.08 | 0.00 | 0.07 | 0.28 | 0.17 |
| ***M*** | 0.07 | 0.09 | 0.06 | 0.23 | 0.27 | 0.25 | 0.04 | 0.07 | 0.09 | 0.12 | 0.16 | 0.17 |
| ***SD*** | 0.09 | 0.12 | 0.10 | 0.16 | 0.27 | 0.26 | 0.08 | 0.11 | 0.19 | 0.14 | 0.25 | 0.25 |
| ***Mdn*** | 0.05 | 0.04 | 0.03 | 0.21 | 0.18 | 0.20 | 0.00 | 0.04 | 0.00 | 0.07 | 0.08 | 0.05 |

*M* = mean; *SD* = standard deviation; *Mdn* = median

**Appendix B2.** *Target Related Error Proportions for Untrained, Related Nouns*

| | Formal | | | Semantic | | | Mixed | | | Phonologically Related Nonword | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ID** | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos |
| PM01PDX | 0.00 | 0.00 | 0.00 | 1.00 | 0.75 | 1.00 | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM01SEA | 0.00 | 0.17 | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.75 | 0.67 | 0.90 |
| PM02PDX | 0.00 | 0.00 | 0.14 | 0.22 | 0.67 | 0.57 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM02SEA | 0.00 | 0.00 | 0.00 | 0.67 | 0.80 | 0.67 | 0.00 | 0.00 | 0.33 | 0.00 | 0.20 | 0.00 |
| PM03SEA | 0.00 | 0.00 | 0.10 | 0.20 | 0.15 | 0.15 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.05 |
| PM04PDX | 0.13 | 0.38 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.08 | 0.00 | 0.19 | 0.00 | 0.25 |
| PM04SEA | 0.18 | 0.19 | 0.00 | 0.12 | 0.06 | 0.15 | 0.00 | 0.00 | 0.08 | 0.47 | 0.31 | 0.00 |
| PM05PDX | 0.00 | 0.00 | 0.17 | 0.67 | 0.40 | 0.33 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.17 |
| PM05SEA | 0.05 | 0.00 | 0.05 | 0.05 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.60 | 0.00 | 0.70 |
| PM06PDX | 0.15 | 0.05 | 0.00 | 0.25 | 0.21 | 0.26 | 0.00 | 0.05 | 0.00 | 0.00 | 0.11 | 0.11 |
| PM06SEA | 0.13 | 0.07 | 0.08 | 0.19 | 0.13 | 0.08 | 0.31 | 0.00 | 0.00 | 0.00 | 0.13 | 0.08 |
| PM07PDX | 0.00 | 0.00 | 0.00 | 0.22 | 0.42 | 0.50 | 0.11 | 0.25 | 0.13 | 0.11 | 0.08 | 0.00 |
| PM07SEA | 0.08 | 0.00 | 0.00 | 0.23 | 0.40 | 0.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 |
| PM08PDX | 0.05 | 0.05 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 | 0.25 |
| PM08SEA | 0.20 | 0.00 | 0.00 | 0.20 | 0.50 | 0.00 | 0.00 | 0.00 | 1.00 | 0.20 | 0.50 | 0.00 |
| PM09PDX | 0.50 | 0.00 | 0.00 | 0.17 | 0.20 | 0.67 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM09SEA | 0.09 | 0.00 | 0.00 | 0.18 | 0.58 | 0.60 | 0.36 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM10PDX | 0.06 | 0.07 | 0.14 | 0.12 | 0.14 | 0.21 | 0.00 | 0.07 | 0.07 | 0.24 | 0.14 | 0.21 |
| PM11PDX | 0.00 | 0.06 | 0.14 | 0.46 | 0.25 | 0.36 | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM11SEA | 0.06 | 0.00 | 0.06 | 0.00 | 0.05 | 0.19 | 0.00 | 0.05 | 0.00 | 0.00 | 0.11 | 0.06 |
| PM12PDX | 0.00 | 0.32 | 0.11 | 0.11 | 0.11 | 0.16 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 |
| PM12SEA | 0.25 | 0.00 | 0.25 | 0.25 | 0.67 | 0.25 | 0.00 | 0.00 | 0.00 | 0.25 | 0.33 | 0.25 |
| PM13SEA | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM14SEA | 0.33 | 0.38 | 0.00 | 0.00 | 0.25 | 0.50 | 0.00 | 0.00 | 0.25 | 0.08 | 0.25 | 0.25 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PM15SEA | 0.00 | 0.00 | 0.17 | 0.57 | 0.45 | 0.33 | 0.00 | 0.18 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM16SEA | 0.10 | 0.00 | 0.00 | 0.60 | 0.67 | 0.67 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM17SEA | 0.11 | 0.00 | 0.00 | 0.11 | 0.67 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM18SEA | 0.05 | 0.11 | 0.06 | 0.21 | 0.06 | 0.19 | 0.00 | 0.11 | 0.00 | 0.05 | 0.11 | 0.06 |
| ***M*** | 0.09 | 0.07 | 0.05 | 0.25 | 0.31 | 0.29 | 0.03 | 0.07 | 0.07 | 0.12 | 0.11 | 0.12 |
| ***SD*** | 0.12 | 0.12 | 0.07 | 0.24 | 0.26 | 0.26 | 0.09 | 0.08 | 0.20 | 0.19 | 0.17 | 0.22 |
| ***Mdn*** | 0.06 | 0.00 | 0.00 | 0.20 | 0.23 | 0.20 | 0.00 | 0.03 | 0.00 | 0.00 | 0.03 | 0.00 |

*M* = mean; *SD* = standard deviation; *Mdn* = median

**Appendix B3.** *Target Related Error Proportions for Untrained, Unrelated Nouns*

| | **Formal** | | | **Semantic** | | | **Mixed** | | | **Phonologically Related Nonword** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ID** | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos |
| PM01PDX | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.25 | 1.00 |
| PM01SEA | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.12 | 0.00 | 1.00 | 0.82 | 0.94 |
| PM02PDX | 0.00 | 0.20 | 0.00 | 0.20 | 0.60 | 0.17 | 0.00 | 0.00 | 0.33 | 0.40 | 0.00 | 0.50 |
| PM02SEA | 0.00 | 0.50 | 0.00 | 0.00 | 0.17 | 0.29 | 0.40 | 0.00 | 0.14 | 0.40 | 0.33 | 0.29 |
| PM03SEA | 0.05 | 0.10 | 0.09 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.04 |
| PM04PDX | 0.18 | 0.33 | 0.23 | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.53 | 0.40 | 0.46 |
| PM04SEA | 0.06 | 0.16 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.50 | 0.26 | 0.15 |
| PM05PDX | 0.11 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.11 | 0.08 | 0.00 | 0.22 | 0.25 | 0.25 |
| PM05SEA | 0.10 | 0.00 | 0.16 | 0.00 | 0.06 | 0.00 | 0.05 | 0.00 | 0.00 | 0.52 | 0.44 | 0.42 |
| PM06PDX | 0.11 | 0.13 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.06 | 0.00 | 0.32 | 0.13 | 0.24 |
| PM06SEA | 0.18 | 0.15 | 0.11 | 0.18 | 0.15 | 0.22 | 0.00 | 0.00 | 0.00 | 0.06 | 0.15 | 0.06 |
| PM07PDX | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.27 | 0.00 | 0.07 | 0.09 | 0.06 | 0.33 | 0.18 |
| PM07SEA | 0.00 | 0.11 | 0.00 | 0.05 | 0.22 | 0.22 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 |
| PM08PDX | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.24 | 0.36 | 0.24 |
| PM08SEA | 0.08 | 0.00 | 0.00 | 0.00 | 0.13 | 0.00 | 0.08 | 0.00 | 0.13 | 0.08 | 0.25 | 0.25 |
| PM09PDX | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.50 | 0.00 | 0.00 | 0.00 | 0.88 | 0.90 | 0.00 |
| PM09SEA | 0.00 | 0.00 | 0.00 | 0.31 | 0.18 | 0.45 | 0.00 | 0.29 | 0.00 | 0.23 | 0.12 | 0.27 |
| PM10PDX | 0.27 | 0.42 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.40 | 0.33 | 0.75 |
| PM11PDX | 0.00 | 0.22 | 0.00 | 0.36 | 0.22 | 0.36 | 0.00 | 0.11 | 0.09 | 0.00 | 0.00 | 0.00 |
| PM11SEA | 0.05 | 0.00 | 0.09 | 0.29 | 0.16 | 0.09 | 0.00 | 0.16 | 0.00 | 0.00 | 0.16 | 0.00 |
| PM12PDX | 0.04 | 0.09 | 0.08 | 0.13 | 0.04 | 0.13 | 0.00 | 0.04 | 0.00 | 0.04 | 0.04 | 0.08 |
| PM12SEA | 0.07 | 0.25 | 0.24 | 0.07 | 0.05 | 0.00 | 0.07 | 0.00 | 0.00 | 0.71 | 0.50 | 0.65 |
| PM13SEA | 0.06 | 0.00 | 0.05 | 0.06 | 0.05 | 0.00 | 0.06 | 0.05 | 0.00 | 0.06 | 0.00 | 0.00 |
| PM14SEA | 0.50 | 0.50 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | 0.25 | 0.75 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PM15SEA | 0.09 | 0.00 | 0.07 | 0.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.18 | 0.38 | 0.29 |
| PM16SEA | 0.43 | 0.14 | 0.00 | 0.43 | 0.29 | 0.17 | 0.00 | 0.14 | 0.00 | 0.00 | 0.14 | 0.67 |
| PM17SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 1.00 | 0.20 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM18SEA | 0.24 | 0.11 | 0.18 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.33 | 0.29 |
| ***M*** | 0.09 | 0.13 | 0.06 | 0.08 | 0.10 | 0.15 | 0.04 | 0.05 | 0.03 | 0.26 | 0.26 | 0.32 |
| ***SD*** | 0.13 | 0.15 | 0.08 | 0.13 | 0.14 | 0.22 | 0.09 | 0.10 | 0.07 | 0.28 | 0.23 | 0.29 |
| ***Mdn*** | 0.06 | 0.10 | 0.02 | 0.00 | 0.05 | 0.06 | 0.00 | 0.00 | 0.00 | 0.20 | 0.25 | 0.25 |

*M* = mean; *SD* = standard deviation; *Mdn* = median

**Appendix C1**. *Target Unrelated Error Proportions for Trained Nouns*

| | **Description** | | | **Unrelated Real Word** | | | **Phonologically Unrelated Nonword** | | | **Miscellaneous** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ID** | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos |
| PM01PDX | 0.36 | 0.00 | 0.11 | 0.00 | 0.00 | 0.11 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM01SEA | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 |
| PM02PDX | 0.41 | 0.18 | 0.27 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.06 | 0.00 |
| PM02SEA | 0.09 | 0.00 | 0.00 | 0.00 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM03SEA | 0.29 | 0.22 | 0.24 | 0.11 | 0.00 | 0.06 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 |
| PM04PDX | 0.03 | 0.08 | 0.08 | 0.06 | 0.00 | 0.00 | 0.06 | 0.04 | 0.08 | 0.03 | 0.04 | 0.00 |
| PM04SEA | 0.00 | 0.00 | 0.14 | 0.03 | 0.13 | 0.14 | 0.03 | 0.00 | 0.21 | 0.00 | 0.00 | 0.00 |
| PM05PDX | 0.08 | 0.07 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 |
| PM05SEA | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.48 | 0.16 | 0.00 | 0.24 | 0.00 |
| PM06PDX | 0.08 | 0.09 | 0.03 | 0.14 | 0.14 | 0.14 | 0.31 | 0.17 | 0.11 | 0.00 | 0.03 | 0.00 |
| PM06SEA | 0.08 | 0.14 | 0.18 | 0.08 | 0.05 | 0.14 | 0.00 | 0.05 | 0.05 | 0.04 | 0.00 | 0.05 |
| PM07PDX | 0.40 | 0.00 | 0.25 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.08 |
| PM07SEA | 0.16 | 0.20 | 0.23 | 0.06 | 0.00 | 0.00 | 0.06 | 0.08 | 0.00 | 0.00 | 0.00 | 0.10 |
| PM08PDX | 0.05 | 0.03 | 0.05 | 0.08 | 0.18 | 0.08 | 0.54 | 0.32 | 0.63 | 0.10 | 0.16 | 0.00 |
| PM08SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM09PDX | 0.04 | 0.08 | 0.00 | 0.00 | 0.00 | 0.10 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM09SEA | 0.19 | 0.13 | 0.18 | 0.10 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM10PDX | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.12 | 0.16 | 0.06 | 0.00 | 0.00 |
| PM11PDX | 0.22 | 0.17 | 0.13 | 0.11 | 0.11 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM11SEA | 0.06 | 0.03 | 0.06 | 0.03 | 0.00 | 0.18 | 0.00 | 0.10 | 0.09 | 0.06 | 0.00 | 0.00 |
| PM12PDX | 0.05 | 0.06 | 0.05 | 0.33 | 0.38 | 0.43 | 0.13 | 0.18 | 0.08 | 0.00 | 0.06 | 0.00 |
| PM12SEA | 0.07 | 0.00 | 0.00 | 0.14 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM13SEA | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PM14SEA | 0.08 | 0.00 | 0.00 | 0.04 | 0.00 | 0.20 | 0.12 | 0.00 | 0.20 | 0.08 | 0.00 | 0.00 |
| PM15SEA | 0.06 | 0.00 | 0.06 | 0.12 | 0.00 | 0.24 | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM16SEA | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM17SEA | 0.35 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM18SEA | 0.07 | 0.04 | 0.00 | 0.20 | 0.16 | 0.10 | 0.23 | 0.12 | 0.07 | 0.00 | 0.00 | 0.00 |
| ***M*** | 0.12 | 0.06 | 0.08 | 0.07 | 0.06 | 0.08 | 0.07 | 0.06 | 0.07 | 0.02 | 0.02 | 0.01 |
| ***SD*** | 0.13 | 0.07 | 0.09 | 0.08 | 0.12 | 0.10 | 0.12 | 0.11 | 0.13 | 0.03 | 0.05 | 0.03 |
| ***Mdn*** | 0.07 | 0.04 | 0.05 | 0.05 | 0.00 | 0.02 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

*M* = mean; *SD* = standard deviation; *Mdn* = median

**Appendix C2.** *Target Unrelated Error Proportions for Untrained, Related Nouns*

| | **Description** | | | **Unrelated Real Word** | | | **Phonologically Unrelated Nonword** | | | **Miscellaneous** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ID** | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos |
| PM01PDX | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM01SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 |
| PM02PDX | 0.56 | 0.33 | 0.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM02SEA | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM03SEA | 0.20 | 0.10 | 0.05 | 0.05 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 |
| PM04PDX | 0.06 | 0.08 | 0.08 | 0.06 | 0.00 | 0.00 | 0.06 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 |
| PM04SEA | 0.00 | 0.00 | 0.15 | 0.00 | 0.13 | 0.00 | 0.06 | 0.06 | 0.31 | 0.06 | 0.00 | 0.00 |
| PM05PDX | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM05SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.10 | 0.39 | 0.15 | 0.00 | 0.33 | 0.00 |
| PM06PDX | 0.05 | 0.00 | 0.11 | 0.05 | 0.11 | 0.21 | 0.40 | 0.37 | 0.26 | 0.00 | 0.00 | 0.00 |
| PM06SEA | 0.06 | 0.13 | 0.15 | 0.00 | 0.07 | 0.08 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 |
| PM07PDX | 0.44 | 0.08 | 0.13 | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 | 0.00 | 0.08 | 0.13 |
| PM07SEA | 0.00 | 0.33 | 0.13 | 0.23 | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM08PDX | 0.05 | 0.00 | 0.00 | 0.10 | 0.15 | 0.15 | 0.71 | 0.60 | 0.50 | 0.00 | 0.05 | 0.05 |
| PM08SEA | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM09PDX | 0.17 | 0.40 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM09SEA | 0.00 | 0.17 | 0.10 | 0.00 | 0.08 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM10PDX | 0.00 | 0.07 | 0.00 | 0.00 | 0.14 | 0.00 | 0.35 | 0.21 | 0.21 | 0.00 | 0.00 | 0.00 |
| PM11PDX | 0.23 | 0.06 | 0.00 | 0.08 | 0.19 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM11SEA | 0.06 | 0.05 | 0.06 | 0.12 | 0.11 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 |
| PM12PDX | 0.00 | 0.00 | 0.00 | 0.21 | 0.26 | 0.53 | 0.05 | 0.00 | 0.05 | 0.00 | 0.32 | 0.00 |
| PM12SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.25 | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 |
| PM13SEA | 0.00 | 0.00 | 0.06 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM14SEA | 0.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PM15SEA | 0.00 | 0.00 | 0.17 | 0.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM16SEA | 0.00 | 0.17 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM17SEA | 0.44 | 0.00 | 0.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM18SEA | 0.05 | 0.00 | 0.00 | 0.37 | 0.33 | 0.25 | 0.05 | 0.11 | 0.06 | 0.05 | 0.00 | 0.06 |
| ***M*** | 0.12 | 0.07 | 0.09 | 0.06 | 0.06 | 0.06 | 0.08 | 0.09 | 0.08 | 0.00 | 0.03 | 0.01 |
| ***SD*** | 0.17 | 0.11 | 0.14 | 0.09 | 0.09 | 0.12 | 0.16 | 0.15 | 0.13 | 0.01 | 0.09 | 0.03 |
| ***Mdn*** | 0.05 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

*M* = mean; *SD* = standard deviation; *Mdn* = median

**Appendix C3.** *Target Unrelated Error Proportions for Untrained, Unrelated Nouns*

| | **Description** | | | **Unrelated Real Word** | | | **Phonologically Unrelated Nonword** | | | **Miscellaneous** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ID** | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos |
| PM01PDX | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM01SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM02PDX | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM02SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 |
| PM03SEA | 0.00 | 0.00 | 0.09 | 0.14 | 0.00 | 0.17 | 0.09 | 0.00 | 0.04 | 0.00 | 0.00 | 0.04 |
| PM04PDX | 0.06 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 |
| PM04SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.25 | 0.00 | 0.11 | 0.05 | 0.00 | 0.00 | 0.05 |
| PM05PDX | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM05SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.05 | 0.17 | 0.26 | 0.05 | 0.33 | 0.00 |
| PM06PDX | 0.00 | 0.06 | 0.00 | 0.00 | 0.31 | 0.18 | 0.32 | 0.06 | 0.35 | 0.00 | 0.06 | 0.00 |
| PM06SEA | 0.06 | 0.00 | 0.00 | 0.06 | 0.00 | 0.17 | 0.00 | 0.15 | 0.11 | 0.00 | 0.00 | 0.00 |
| PM07PDX | 0.56 | 0.27 | 0.27 | 0.13 | 0.07 | 0.09 | 0.19 | 0.07 | 0.09 | 0.06 | 0.07 | 0.00 |
| PM07SEA | 0.16 | 0.06 | 0.22 | 0.00 | 0.00 | 0.06 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.11 |
| PM08PDX | 0.08 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.60 | 0.44 | 0.72 | 0.04 | 0.12 | 0.00 |
| PM08SEA | 0.08 | 0.00 | 0.00 | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.25 |
| PM09PDX | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM09SEA | 0.15 | 0.00 | 0.00 | 0.08 | 0.06 | 0.00 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 |
| PM10PDX | 0.07 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 |
| PM11PDX | 0.45 | 0.00 | 0.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.09 | 0.00 | 0.00 | 0.00 |
| PM11SEA | 0.00 | 0.05 | 0.00 | 0.10 | 0.00 | 0.18 | 0.14 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM12PDX | 0.00 | 0.00 | 0.00 | 0.17 | 0.22 | 0.46 | 0.09 | 0.26 | 0.04 | 0.04 | 0.13 | 0.00 |
| PM12SEA | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.10 | 0.06 |
| PM13SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM14SEA | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PM15SEA | 0.09 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 |
| PM16SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM17SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM18SEA | 0.05 | 0.00 | 0.00 | 0.33 | 0.28 | 0.18 | 0.14 | 0.11 | 0.12 | 0.00 | 0.00 | 0.00 |
| ***M*** | 0.06 | 0.02 | 0.03 | 0.04 | 0.05 | 0.09 | 0.06 | 0.06 | 0.08 | 0.01 | 0.03 | 0.03 |
| ***SD*** | 0.13 | 0.05 | 0.08 | 0.08 | 0.09 | 0.14 | 0.13 | 0.10 | 0.15 | 0.03 | 0.07 | 0.06 |
| ***Mdn*** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

*M* = mean; *SD* = standard deviation; *Mdn* = median

**Appendix D.** *Omission Error Proportions for Trained, Untrained-Related, and Untrained-Unrelated Nouns*

| | **Trained Nouns** | | | **Untrained, Related Nouns** | | | **Untrained, Unrelated Nouns** | | |
|---|---|---|---|---|---|---|---|---|---|
| **ID** | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos | Pre-tx | Post-tx | 3Mos |
| PM01PDX | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.75 | 0.00 |
| PM01SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM02PDX | 0.09 | 0.00 | 0.18 | 0.22 | 0.00 | 0.14 | 0.40 | 0.00 | 0.00 |
| PM02SEA | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.14 |
| PM03SEA | 0.39 | 0.63 | 0.42 | 0.55 | 0.70 | 0.50 | 0.73 | 0.81 | 0.43 |
| PM04PDX | 0.42 | 0.19 | 0.20 | 0.50 | 0.38 | 0.50 | 0.18 | 0.07 | 0.23 |
| PM04SEA | 0.60 | 0.38 | 0.29 | 0.12 | 0.25 | 0.31 | 0.44 | 0.37 | 0.45 |
| PM05PDX | 0.23 | 0.29 | 0.50 | 0.17 | 0.40 | 0.33 | 0.56 | 0.58 | 0.75 |
| PM05SEA | 0.49 | 0.00 | 0.03 | 0.20 | 0.22 | 0.05 | 0.24 | 0.00 | 0.05 |
| PM06PDX | 0.17 | 0.14 | 0.31 | 0.10 | 0.11 | 0.05 | 0.26 | 0.19 | 0.18 |
| PM06SEA | 0.46 | 0.33 | 0.27 | 0.31 | 0.47 | 0.46 | 0.47 | 0.38 | 0.33 |
| PM07PDX | 0.00 | 0.00 | 0.08 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 |
| PM07SEA | 0.39 | 0.36 | 0.43 | 0.46 | 0.20 | 0.56 | 0.74 | 0.56 | 0.28 |
| PM08PDX | 0.13 | 0.03 | 0.03 | 0.00 | 0.05 | 0.00 | 0.04 | 0.04 | 0.00 |
| PM08SEA | 0.22 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.58 | 0.50 | 0.38 |
| PM09PDX | 0.00 | 0.08 | 0.00 | 0.00 | 0.20 | 0.00 | 0.06 | 0.10 | 0.00 |
| PM09SEA | 0.24 | 0.00 | 0.09 | 0.27 | 0.00 | 0.30 | 0.23 | 0.35 | 0.18 |
| PM10PDX | 0.12 | 0.00 | 0.06 | 0.24 | 0.14 | 0.14 | 0.20 | 0.17 | 0.00 |
| PM11PDX | 0.22 | 0.11 | 0.09 | 0.23 | 0.25 | 0.50 | 0.18 | 0.33 | 0.18 |
| PM11SEA | 0.58 | 0.50 | 0.44 | 0.76 | 0.63 | 0.44 | 0.43 | 0.42 | 0.64 |
| PM12PDX | 0.41 | 0.06 | 0.27 | 0.58 | 0.00 | 0.16 | 0.48 | 0.17 | 0.21 |
| PM12SEA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.06 |
| PM13SEA | 0.91 | 0.93 | 0.94 | 0.85 | 1.00 | 0.89 | 0.69 | 0.91 | 0.95 |
| PM14SEA | 0.12 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.25 | 0.00 |
| PM15SEA | 0.47 | 0.25 | 0.29 | 0.29 | 0.36 | 0.33 | 0.36 | 0.63 | 0.57 |
| PM16SEA | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.17 | 0.14 | 0.29 | 0.00 |
| PM17SEA | 0.06 | 0.00 | 0.00 | 0.33 | 0.00 | 0.33 | 0.80 | 0.20 | 0.00 |
| PM18SEA | 0.17 | 0.12 | 0.41 | 0.16 | 0.17 | 0.31 | 0.05 | 0.17 | 0.24 |
| ***M*** | 0.25 | 0.16 | 0.19 | 0.24 | 0.20 | 0.23 | 0.34 | 0.30 | 0.22 |
| ***SD*** | 0.23 | 0.23 | 0.22 | 0.24 | 0.25 | 0.23 | 0.28 | 0.27 | 0.26 |
| ***Mdn*** | 0.19 | 0.07 | 0.09 | 0.21 | 0.12 | 0.16 | 0.25 | 0.23 | 0.18 |

*M* = mean; *SD* = standard deviation; *Mdn* = median