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Word Repetition and Retrieval Practice Effects in Aphasia: Evidence for Use-dependent Learning in Lexical Access

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Abstract

This study tested the hypothesis that a use-dependent learning mechanism operates at each of two stages of lexical access: retrieval of a word from semantics (“Stage 1”), followed by retrieval of the word’s constituent phonemes (“Stage 2”). Two participants with aphasia were selected due to their contrasting types of naming impairment (Stage 1 versus Stage 2 difficulty). For each participant, items were assigned to naming training that involved retrieval practice (retrieval of the name from semantics) or repetition practice (hear the name and orally repeat it). Naming tests were administered one day and one week after training. The results supported the predicted training effects: (1) Because successful naming via retrieval practice requires both Stage 1 and Stage 2, this technique uses and strengthens item-specific connections in both stages. (2) Because word repetition circumvents semantically-driven retrieval, this technique primarily uses and strengthens item-specific connections in Stage 2.

Keywords

aphasia; retrieval practice; errorless learning; naming; repetition; lexical access

Introduction

A ubiquitous problem for people with aphasia is difficulty retrieving words for oral production, including names for common objects, actions, and people (i.e., naming impairment). Naming impairment can manifest as different types of speech errors, including semantic errors (e.g., “piano” for “accordion”) and phonological errors (e.g., “gubbles” for “goggles”). Behavioral and computational investigations of such speech errors in aphasia have made important contributions to our knowledge of lexical access. A better understanding of lexical access can in turn guide treatment decisions to ameliorate naming impairment in aphasia. In the present study, we examined the naming performance of two individuals with aphasia with contrasting types of naming impairment to address both theoretical and clinical aims. First, expanding on emerging theories of learning in language production, we aimed to test the hypothesis that the use of a specific stage of lexical access

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Disclosure of Interest

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exerts persistent changes on the language system at that stage. In the context of this paper, “persistent” change refers to learning effects that last on the order of minutes, hours, or days, as opposed to transient changes in activation levels that dissipate within seconds (see Oppenheim, Dell, & Schwartz, 2010). Second, we aimed to determine whether two common naming treatment techniques (repetition practice and retrieval practice) differentially promote improvement in naming in aphasia as a function of an individual’s locus of naming deficit, which would inform ways to structure treatment to be maximally beneficial.

Models of Lexical Access and Learning

Across different theories of lexical access, there is general consensus that naming (i.e., retrieving the name for an entity) involves at least partially independent stages dedicated to (1) the retrieval of a semantic-syntactic lexical representation (hereafter, “word”), followed by (2) the retrieval of the phonological form of the word (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Levelt, Roelofs, & Meyer, 1999; Rapp & Goldrick, 2000). In particular, an interactive two-step model of lexical access (see Figure 1) has been successful in simulating naming accuracy and error types in aphasia by manipulating the strength (i.e., “weight”) of connections between semantics and words in Stage 1 and/or between words and output phonology in Stage 2 (Foygel & Dell, 2000; Schwartz, Dell, Martin, Gahl, & Sobel, 2006). This and other two-stage frameworks are useful for explaining many aspects of naming behavior for both typical and aphasic speakers, but they have yet to implement mechanisms of long-lasting change in lexical access to account for learning and recovery.

According to separate (but not mutually exclusive) accounts of lexical access, each act of speech is a learning event that exerts persistent change, even in the adult language system (Damian & Als, 2005; Howard, Nickels, Coltheart, & Cole-Virtue, 2006; Oppenheim et al., 2010). Consistent with this hypothesis, studies of semantic interference find that retrieval of a word leads to greater difficulty in subsequent retrieval of a semantically related word (e.g., Belke, Meyer, & Damian, 2005; Damian, Vigliocco, & Levelt, 2001; Kroll & Stewart, 1994). This interference accumulates with each additional retrieval of a semantically related word but remains relatively insensitive to intervening unrelated words or the passage of time (Damian & Als, 2005; Howard et al., 2006; Hsiao, Schwartz, Schnur, & Dell, 2009; Schnur, 2014). The durable effects of semantic context support the conclusion that each speech act confers use-dependent, persistent change impacting the processes underlying language production.

Central to models of learning in lexical access is the notion that change is generated from attempting to use a pathway. For example, in Oppenheim et al.’s (2010) model, an error signal is generated by the discrepancy between the desired activation of a word given the input from semantics and the actual activation of the word that resulted from a retrieval attempt. This error signal drives learning by dictating how the weight of a specific connection between a semantic feature and a word is changed. In this way, each retrieval attempt increases connection weights from semantic features to the target word, thereby facilitating access to the word in the future, and decreases weights from semantic features to all other activated words, thereby reducing access to the target word’s semantic competitors. To date, these use-dependent learning frameworks (Damian & Als, 2005; Howard et al., 2006; Oppenheim et al., 2010) have focused on such changes in semantic-to-lexical connections (Stage 1 in a two-stage model), likely because modeling learning in this stage is most relevant to the goal of explaining semantic interference effects. However, Breining, Nozari, & Rapp (2016) found that phonological and orthographic segmental overlap (e.g., *cat* in the context of *mat*, *cot*, *cap*, *map*, *mop*) also gives rise to interference effects in naming, suggesting that use-dependent learning mechanisms apply across stages and modalities of word production. In the present study, we examined the possibility of a two-stage, use-dependent learning framework by testing the effects of repetition practice and retrieval practice, two naming treatment techniques that provide different opportunities for a patient to use the two stages of lexical access.

Repetition Practice versus Retrieval Practice in Naming Treatment

Although oral repetition of names is often used in combination with other naming treatment techniques, certain interventions for people with aphasia rely solely on repetition. The basic assumption that motivates this type of intervention is that making a response to a particular stimulus increases the likelihood of making that response to the stimulus in the future, irrespective of whether the produced response was accurate. Hence, errors made during training would be reinforced and decrease treatment efficacy, particularly for individuals with cognitive impairments that disrupt explicit memory (Baddeley & Wilson, 1994; Evans et al., 2000; Wilson & Evans, 1996). Following from these ideas, repetition-based “errorless learning” approaches in aphasia treatment aim to avoid erroneous responses by eschewing opportunities for self-generated naming responses. Instead, they bolster associations between depicted objects and their corresponding names via repeated exposure to and oral repetition of the names by the patient (for reviews, see Fillingham, Hodgson, Sage, & Lambon Ralph, 2003; Middleton & Schwartz, 2012). Several naming treatment studies have compared the effects of errorless learning versus “errorful” learning that encourages self-generated naming responses, primarily concluding that the two training approaches are equally beneficial for many people with aphasia (Conroy, Sage, & Lambon Ralph, 2009; Fillingham, Sage, & Lambon Ralph, 2005a, 2005b, 2006; McKissock & Ward, 2007).

However, the use of self-generated naming attempts in aphasia treatment is in line with a large body of cognitive psychology research on the effects of retrieval practice (i.e., test-enhanced learning) that shows that providing opportunities to retrieve information from long-term memory results in robust learning of that information (see Karpicke, Lehman, & Aue, 2014; Rowland, 2014). In the standard paradigm for demonstrating learning from retrieval practice, initial familiarization of target information is followed either by further study opportunities (i.e., restudy) or by tests in which participants attempt to retrieve the information from long-term memory (i.e., retrieval practice). A robust finding in the literature is that performance on a post-training retention test is greater following retrieval practice versus restudy. This effect is reliable even in studies that do not provide correct-answer feedback after retrieval attempts, although larger effects are found when feedback is provided (Rowland, 2014).

Recently, the effects of repetition practice and retrieval practice on naming in aphasia were directly compared in studies modeled after the standard retrieval practice paradigm

(Middleton, Schwartz, Rawson, & Garvey, 2015; Middleton, Schwartz, Rawson, Traut, & Verkuilen, 2016). Initial familiarization of the target information (i.e., the target name) consisted of presenting the name with the depicted object and asking the participant to repeat the name. Following initial familiarization, training involved repetition practice, in which a pictured object and its name were presented for repetition by the participant (analogous to the restudy condition in the standard paradigm), or retrieval practice, in which the participant was given an opportunity to retrieve the name for the picture. In both studies, an advantage for retrieval practice versus repetition practice was found on tests of naming administered one day and one week following training. A retrieval practice advantage was also observed one month and four months after training in a study that compared testing (i.e., retrieving names) versus studying (i.e., repeating names) for three individuals with aphasia (Friedman, Sullivan, Snider, Luta, & Jones, 2017). This evidence suggests that the benefits of retrieval practice may outweigh those of repetition practice when considering long-term retention of naming training benefits. However, a better understanding of how each type of practice exerts changes in lexical access could help inform ways to structure treatment to be maximally beneficial for each individual with aphasia.

The Present Study

For the purposes of this study, the critical difference between retrieval practice and repetition practice is that retrieval practice provides opportunities for naming as well as repeating words (when initial familiarization and/or feedback involves repetition), whereas repetition practice only provides opportunities for repeating words. Hence, measuring the effects of these two training approaches provides a means to test the two-stage, use-dependent learning hypothesis: instances of naming should strengthen item-specific connections in both stages of lexical access by providing opportunities to map from semantics to the appropriate word and from the word to output phonology, whereas instances of oral repetition do not require mapping from semantic features to words and therefore should have a weaker effect on Stage 1 connections compared to naming (see Figure 1). Instances of oral repetition may consist of activating the word via auditory and/or orthographic input and then mapping to output phonology (a lexical-route model), by mapping directly from input to output phonology (a nonlexical-route model), or using both routes (a dual-route model) (Dell, Martin, & Schwartz, 2007; Hanley, Dell, Kay, & Baron, 2004; Hanley, Kay, & Edwards, 2002; Hillis & Caramazza, 1991; Nozari & Dell, 2013; Nozari, Kittredge, Dell, & Schwartz, 2010). We provide evidence in the Participants section below that the participants in the present study used (at least in part) a lexical route when repeating words, in which case repetition should strengthen Stage 2 connections by providing opportunities to map from words to output phonology.

In the present study, we examined the effects of repetition practice and retrieval practice on the post-training naming performance of two individuals with chronic aphasia who were selected due to their contrasting types of naming impairment. One participant (P1) presented with a symptom profile indicative of impairment in Stage 1 word retrieval and relatively intact Stage 2 phonological processes. The other participant (P2) presented with a symptom profile indicative of impairment in Stage 2 phonological processes and relatively intact Stage 1 word retrieval. For each individual, we (1) selected pictures of common objects that elicited incorrect naming responses, (2) assigned these items in a matched fashion to training conditions involving repetition practice versus retrieval practice, and (3) tested naming of the items one day (Test 1) and one week (Test 2) after training. Test 1 served as the primary test of the training effects. Because participants' naming attempts at Test 1 constitute retrieval practice (albeit without feedback), any subsequent tests reflect the effect of this post-training retrieval practice in addition to the effect of the initial training condition. This is important to consider because after an initial training session, the effect of one or more additional sessions of retrieval practice can "override" (i.e., reduce the differences between) the initial training conditions (Rawson & Dunlosky, 2011, 2013; Vaughn, Dunlosky, & Rawson, 2016). We included Test 2 at one week post-training because longer retention intervals are more informative for the clinical aims of the study, but we refrain from making strong predictions regarding performance at Test 2 due to the potential influence of the participants' naming experience at Test 1.

Hence, the key predictions for this study relate to naming accuracy at Test 1. Following from the two-stage, use-dependent learning hypothesis, we predicted that retrieval practice should result in higher post-training naming accuracy than repetition practice if weakened Stage 1 connections are the primary impairment (i.e., P1), whereas the two types of training should yield similar benefits for post-training naming if weakened Stage 2 connections are the primary impairment (i.e., P2).

One complicating factor for these predictions is that the rate of correct responding at training is typically greater for repetition compared to naming trials, leading to greater accuracy during repetition practice compared to retrieval practice. Accuracy during repetition practice may be superior for a number of reasons. In contrast to naming trials, in which Stage 1 retrieval may fail at times, on each repetition trial the provision of the auditory and/or orthographic form of the word activates the word, satisfying a prerequisite for lexically-guided target phoneme retrieval. In addition, on repetition trials and not naming trials, hearing the word provides—and may induce persistent strengthening of—auditory syllable targets, which some models suggest is an important aspect of word production (e.g., Walker & Hickok, 2016). Although the predictions under consideration do not apply to performance on the training trials themselves, training accuracy may influence post-training outcomes. Current use-dependent learning models (Damian & Als, 2005; Howard et al., 2006; Oppenheim et al., 2010) are underspecified regarding whether the target word or target phonemes are strengthened less (or at all) when use of the pathway results in error rather than correct retrieval. However, theories of repetition-based errorless learning and retrieval practice both suggest that accurate responding during training is important for long-term behavioral change. Theories of errorless learning emphasize the detrimental effects of unsuccessful retrieval attempts via the reinforcement of errors (Fillingham et al., 2003); retrieval practice research supports the necessity of successful retrieval attempts to induce the full benefits of retrieving information from long-term memory (Jang, Wixted, Pecher, Zeelenberg, & Huber, 2012; Kornell, Bjork, & Garcia, 2011; Rowland, 2014; Rowland & DeLosh, 2015).

Assuming that successful retrieval at a stage of lexical access enhances learning compared to errorful retrieval, we still expect P1 (with Stage 1 impairment) to show greater post-training naming performance following retrieval practice relative to repetition practice. Although it is possible that errors could weaken the benefits of retrieval practice, this training condition should result in at least some instances of successful word retrieval, whereas repetition practice provides no opportunities for semantically-driven word retrieval. In the case of P2, however, we may expect greater (not just equal) benefits from repetition practice relative to retrieval practice if correct responding is higher during repetition compared to naming. Whether repetition practice results in equal or greater benefits for P2, we predict a significant interaction between the two participants and the two training conditions.

Method

Participants

The participants were two native English speakers with chronic stroke-induced aphasia (P1 and P2). These participants were selected to be maximally distinct with regard to the underlying cause of naming impairment and matched in overall severity of aphasia. The demographic and linguistic profiles of the participants are summarized below, with selected test scores presented in Table 1. For comparison, Table 1 includes average scores from samples of neurologically intact older adults. Both participants were within a normal range on an audiometric screening and had normal or corrected-to-normal vision. Neither participant showed evidence of apraxia of speech, as evaluated by the ABA-2: Apraxia Battery for Adults (Dabul, 2000). Participants gave informed consent under a protocol approved by the Institutional Review Board of Einstein Healthcare Network and were paid at a rate of $15 per hour.

P1—P1 was a 53-year-old woman with 18 years of education who had a left-hemisphere stroke 11 years prior to participating in the study. Her classification by the Western Aphasia Battery (WAB; Kertesz, 2007) was anomic aphasia, consistent with further language testing showing word-finding difficulties and relatively intact comprehension and repetition abilities. Naming errors for P1 primarily consisted of omissions (i.e., failure to provide a naming attempt, including descriptions of the item and personal comments) and semantic errors (see Table 1 for percentages of error types produced on the Philadelphia Naming Test and Object Naming Corpus).

Omissions and semantic errors in naming may result from impairment to the semantic representations themselves, access to those representations, and/or from impaired lexical access (Gainotti, Miceli, Caltagirone, Silveri, & Masullo, 1981; Hillis, Rapp, Romani, & Caramazza, 1990; Jefferies & Lambon Ralph, 2006; Schwartz et al., 2009). P1 exhibited mild deficits on tasks requiring knowledge of semantic associations, scoring numerically lower than healthy older adults (see Table 1 for scores on Pyramids and Palm Trees, Camel and Cactus, and Synonymy Triplets Test). These scores, together with her only mildly impaired language comprehension, suggest that semantic impairment was not the primary cause of P1’s naming difficulty. With regard to lexical access impairment, omissions in naming may indicate Stage 1 word retrieval difficulty (Dell, Lawler, Harris, & Gordon, 2004; Chen, Middleton, & Mirman, in press) or impaired access to output phonology in Stage 2, for example in tip-of-the-tongue states (e.g., Badecker, Miozzo, & Zanittini, 1995;

Beeson, Holland, & Murray, 1997; Goodglass, Kaplan, Weintraub, & Ackerman, 1976). Semantic errors in naming are typically associated with incorrect mapping from semantics to words in Stage 1 (Schwartz et al., 2006), although in some cases they may arise due to deficits in phonological output (Caramazza & Hillis, 1990). However, P1 rarely produced phonological errors in naming or repetition that would reflect Stage 2 impairment. For example, her accuracy on the Philadelphia Repetition Test was 99%. Hence, P1's profile implicated Stage 1 impairment as the primary cause of naming difficulty.

P2—P2 was a 70-year-old man with 19 years of education who had a left-hemisphere stroke two years prior to participating in the study. His classification by the WAB was conduction aphasia, consistent with further language testing showing relatively intact comprehension, impaired repetition of words and nonwords, and phonological errors comprising the majority of naming failures on the Philadelphia Naming Test and Object Naming Corpus (see Table 1).

Phonological errors can result from impairments in lexical access, post-lexical phonemic buffering/sequencing, and/or phonetic/articulatory processes (Goldrick & Rapp, 2007; Romani & Galluzzi, 2005; Romani, Galluzzi, & Olson, 2011; Shallice, Rumiati, & Zadini, 2000). In the context of Schwartz et al.'s (2006) two-step interactive model of lexical access, formals (i.e., phonologically related word errors) can arise in Stage 1, with feedback from the phonological level resulting in the selection of a word that is phonologically related to the target, or in Stage 2, with incorrect phoneme retrieval forming a word rather than a nonword by chance. Hence, we cannot completely rule out some degree of phonological difficulty originating at Stage 1. However, the majority of P2's phonological errors in naming and repetition were nonwords, which are associated with Stage 2 impairment in the two-step model. For example, nonwords constituted 75% of P2's phonological error responses on the Object Naming Corpus. In addition, the results of a logistic regression model showed a significant effect of lexical frequency, controlling for word length, on P2's accuracy on the Philadelphia Repetition Test, *Estimate* = 0.84, $z = 2.02$, $p < .05$. Because lexical frequency primarily affects retrieval of a word's phonological form (Goldrick & Rapp, 2007; Jescheniak & Levelt, 1994; Kittredge, Dell, Verkuilen, & Schwartz, 2008), we interpret this effect as evidence of difficulty at Stage 2 of lexical access. Although it is difficult to rule out some contribution of post-lexical processes, P2 did not exhibit impairment at a phonetic/articulatory level. He passed the ABA-2 screen for apraxia of speech and produced phonetic errors (e.g., phonemes produced with audible effort or distortion) on only 6% of words in the Philadelphia Repetition Test. Hence, P2's profile indicated that his naming impairment primarily originated subsequent to Stage 1 word retrieval and prior to articulatory processes, including Stage 2 impairment. Compared to P1, however, P2's impairment was less purely localized to a single stage of naming, as evidenced by his production of semantic errors on 7% of items in the Object Naming Corpus (see Table 1). We return to this issue in the Results and Discussion sections.

Repetition—In this study, we assume that the participants use lexical-phonological connections when they repeat words. Nozari & Dell (2013) provided evidence that (1) when an individual with aphasia is unable to access the meaning of a word, the nonlexical route is used for repetition, and (2) when the nonlexical route for repetition is weak, it is not used. Regarding the first point, P1 and P2 scored highly on tests of word comprehension. There is no indication that these individuals were unable to access the meaning of the words in the repetition task in the present study, particularly considering that the corresponding picture was presented with each word (see Stimuli and Procedures sections below). Hence, the nonlexical route would not be required for repetition. Regarding the second point, P2 scored particularly low on a test of non-word repetition that requires the nonlexical route (22%) in comparison with his performance on a test of word repetition (81%). Hence, P2 was unlikely to use the weak nonlexical route when repeating words. As noted above, P2 also showed a significant effect of lexical frequency on word repetition accuracy, which is consistent with the use of a lexical route for repetition. For these reasons, we assume that P1 and P2 used lexical-phonological connections when repeating words, although we cannot rule out all contributions from the nonlexical route.

Stimuli

Pictures of 660 common objects were selected from published picture corpora (Szekely et al., 2004) and Internet sources. Visual complexity and name agreement values were obtained from published corpora when available or from normative studies with at least 40 responses per item. Frequency values (log frequency per million) for the names of the objects were obtained from the $\text{SUBTLEX}_{\text{US}}$ project (Brysbaert & New, 2009). Audio recordings of the names were created by a female native English speaker and normalized in volume. All stimuli were presented on a PC computer using E-Prime software.

Response Coding

Participant responses in all phases of the experiment were recorded, transcribed, and coded for accuracy and error type according to a modified version of the coding system established for the Philadelphia Naming Test (Roach, Schwartz, Martin, Grewal, & Brecher, 1996). A response was coded as correct if the first complete utterance matched the target response, with all the correct phonemes in the correct order. Primary error types included the following: (1) omission, defined as a failure to provide a naming attempt, including descriptions of the item and personal comments, (2) semantic error, defined as a noun related to the target by category or thematic association, and (3) phonological error, defined as a semantically unrelated word or nonword that shares more than one phoneme with the target or a single phoneme in the same position compared to the target (e.g., the onset).

Procedures

Item Selection—The initial item selection phase was designed to identify words that elicited naming difficulty for each individual participant. The Object Naming Corpus of 660 pictures was administered in random order twice, with the two administrations occurring in separate weeks. Participants were instructed to name each picture. The experimenter advanced the trial when the participant pointed to a “thumbs up” picture indicating that they had given their final answer or after 20 seconds if a final answer was not provided. For the purposes of a separate study, auditory and visual presentation of the name was provided for the participant to repeat after a randomly selected 50% of trials in the first administration of the corpus. This initial presentation of feedback was not expected to influence training outcomes in the present study because approximately one month elapsed between the item selection phase and the beginning of training. Nevertheless, the number of items that received feedback was matched across training conditions and across participants during item assignment.

Any item that elicited an error in at least one of the two administrations of the corpus was identified as a potential item for that participant's personalized training set. For each participant, 216 items were divided evenly into the repetition practice and retrieval practice training conditions, matching as closely as possible for variables known to impact naming performance, including pre-training accuracy (see Table 2). A logistic regression model with the fixed effects of participant (P1 versus P2) and training condition (repetition practice versus retrieval practice) showed that the number of items named correctly in one of the two pre-training administrations did not significantly differ across participants, *Estimate* = 0.08, *SE* = 0.20, $p = .69$, or across conditions, *Estimate* = 0.08, *SE* = 0.20, $p = .69$. Error type was not a factor in item selection; the error profile for the trained items for each participant (see Table 2b) was representative of the errors they produced for the entire Object Naming Corpus. Appendix A provides a detailed report of error types produced at pre-training and at post-training.

Main Experiment—Each participant completed the main experiment in a protocol that involved three cycles of training and testing over several weeks, with different items assigned to each cycle. Each cycle consisted of three sessions: (1) a training session, (2) a naming test for the trained items administered one day after training (hereafter, "Test 1"), and (3) a naming test for the trained items administered one week after training (hereafter, "Test 2"). Test 2 was always completed before the next cycle began. Each training session consisted of one block of repetition practice and one block of retrieval practice. Thirty-six items were assigned to each block of training, for a total of 216 items per participant across the three cycles of the study. The order of repetition practice versus retrieval practice was partially counterbalanced across the training sessions[1].

In the repetition practice condition, each item was presented for four repetition trials. On a repetition trial, the picture of the object was presented simultaneously with the written and auditory forms of the name. The participant was instructed to repeat the name once. The picture and written name remained on the computer monitor for 8 seconds. After that time, feedback was provided (i.e., the auditory and written forms of the name were presented again for the participant to repeat).

In the retrieval practice condition, the first trial for an item was a repetition trial, which is analogous to an initial familiarization trial in standard procedures used in retrieval practice research. Unlike the repetition practice condition, however, the subsequent three trials were naming trials. On a naming trial, the picture was presented, and the participant attempted to

[1]Training began with the retrieval practice block in the first and third cycles of the study and with the repetition practice block in the second cycle. Post-hoc logistic regression analyses did not indicate a significant effect of training order on naming accuracy at Test 1 (*Estimate* = -0.34, *SE* = 0.21, $p = 0.10$) or at Test 2 (*Estimate* = -0.31, *SE* = 0.20, $p = 0.11$).

name the picture. After 8 seconds, feedback was provided (i.e., the auditory and written forms of the name were presented again for the participant to repeat).

Thus, both conditions provided opportunities for name repetition, but only the retrieval practice condition provided opportunities for self-generated naming attempts. All trials in both the repetition practice and retrieval practice conditions ended in feedback (repetition of the target name), and the timing of the trials was matched across conditions. In both training conditions, five intervening items were administered between each of the four trials for a given item. The procedures for Test 1 and Test 2 were identical to the item selection phase (i.e., the participant was given 20 seconds to try to name each picture), with no feedback administered.

Data Analysis

For each participant, data from the three cycles of the experiment were combined for analysis. For example, data for each participant's Test 1 included responses from three separate naming sessions, each administered one day after their respective training session. Analyses were performed using the glm function (family = binomial) in R version 3.1.2 (R Core Team, 2014) with alpha = 0.05 for tests of significance. In the following section, training performance is reported but not statistically compared across conditions because the responses for training trials 2-4 for each item in the retrieval practice condition (i.e., naming attempts) differed qualitatively from responses in the repetition practice condition (i.e., repetition attempts). The effects of the training conditions on post-training naming accuracy were analyzed using logistic regression models with naming accuracy as the binary outcome variable (correct or incorrect).

Test 1 served as the primary outcome measure for evaluating the study predictions. At Test 1, we predicted a significant interaction between the two-level factor of condition (repetition practice versus retrieval practice) and the two-level factor of participant (P1 versus P2), which would indicate that the effects of the training conditions were significantly different between the two participants. In addition, we tested the simple effects of training condition on accuracy with separate models for each participant. To examine whether the differential training effects persisted at a longer (one-week) retention interval, we tested the interaction between condition and participant at the follow-up Test 2. In addition, heterogeneity in P2's naming error profile afforded an opportunity to examine our predictions at the level of individual items in a secondary post-hoc analysis. Further details of this analysis are provided in the following Results section.

Results

Training

Figure 2 displays the participants' accuracy during training. These data reflect repetition accuracy for all trials in the repetition practice condition and for the first trial of each item in the retrieval practice condition; the data reflect naming accuracy for trials 2-4 in the retrieval practice condition. P1's average repetition accuracy in the repetition practice condition (99.8%) and average naming accuracy in the retrieval practice condition (97%) were near ceiling performance. P2's average repetition accuracy in the repetition practice condition (87%) was numerically higher than his average naming accuracy in the retrieval practice condition (78%), as expected because repetition accuracy is typically higher than naming accuracy.

Assessment of Predicted Training Effects (Test 1)

Figure 3a displays average naming accuracy one day after training for the two participants. The interaction between training condition and participant was significant, *Estimate* = −0.28, *SE* = 0.11, $p < .05$, indicating that the two training conditions had different effects on naming accuracy for P1 compared to P2 (see Table 3a). For P1, retrieval practice resulted in significantly higher accuracy than repetition practice, *Estimate* = 1.01, *SE* = 0.34, $p < .01$. For P2, there was no significant difference between the two conditions, *Estimate* = −0.11, *SE* = 0.28, $p = .68$.

Follow-up Assessment of Training Effects (Test 2)

Figure 3b displays average naming accuracy one week after training for the two participants. The interaction between training condition and participant was not significant, *Estimate* = 0.01, *SE* = 0.10, $p = .89$, indicating similar effects of the two conditions for P1 and P2 (see Table 3b). Across the two participants, retrieval practice resulted in significantly higher accuracy at Test 2 than repetition practice, *Estimate* = −0.24, *SE* = 0.10, $p < .05$. When analyzing data for each participant separately, however, the advantage of retrieval practice over repetition practice did not reach statistical significance for P1, *Estimate* = 0.45, *SE* = 0.29, $p = .12$, or for P2, *Estimate* = 0.50, *SE* = 0.28, $p = .07$.

Error Analysis for P2

Despite our efforts to identify participants with impairments isolated to one stage of naming, P2's naming error profile indicated some degree of impairment at Stage 1 as well as at Stage 2 (see Table 1). Because error type was not a factor in item selection, 27% of pre-training naming responses for the items included in P2's training set were errors *other than* phonological errors (see Appendix A). This variability adds noise to the design of the present study, which assumed that P2's items elicited difficulty at Stage 2. As a secondary analysis, we identified 32 trained items for P2 that elicited errors other than phonological errors (the majority were semantic errors) at both of the pre-training administrations of the Object Naming Corpus. Although small in number, we have relatively high confidence that these items elicited difficulty at Stage 1 for P2 (hereafter, "Stage-1 items"). We also identified 75 items that elicited a phonological error at both of the two pre-training administrations. Hence, we have relatively high confidence that these items elicited difficulty at Stage 2 for P2 (hereafter, "Stage-2 items"). Based on the two-stage, use-dependent learning hypothesis, we would expect the Stage-1 items to benefit from retrieval practice to a greater extent than repetition practice, whereas Stage-2 items should benefit equally or more from repetition practice.

To examine whether the two training conditions differentially affected the two types of items for P2, we conducted logistic regression models testing the interaction between training condition and item type on naming accuracy at Test 1 and at Test 2. The results indicated a significant interaction at Test 1, *Estimate* = −0.53, *SE* = 0.23, $p < .05$ (see Table 3c). In line with the predicted effects, the interaction reflected numerically higher accuracy in the retrieval practice condition for the Stage-1 items and numerically higher accuracy in the repetition practice condition for the Stage-2 items (see Figure 4a). The differences between training conditions were relatively small at Test 2 (see Figure 4b), so that there was no significant interaction between training condition and item type, *Estimate* = 0.15, *SE* = 0.22, $p = .50$ (see Table 3d).

Discussion

We hypothesized that naming strengthens item-specific connections in both stages of lexical access by providing opportunities to map from meaning to the word and from the word to output phonology, whereas oral repetition primarily strengthens Stage 2 connections because it bypasses Stage 1 mapping. Hence, we predicted that an individual with Stage 1 impairment (P1) should achieve greater naming accuracy for items trained under retrieval practice (which provides opportunities for naming) compared to repetition practice conditions (which only provides opportunities for repetition), whereas an individual with Stage 2 impairment (P2) should achieve similar or greater naming accuracy for items trained under repetition practice compared to retrieval practice conditions. The results of this study provide preliminary support for the hypothesis that the use of a specific stage of lexical access exerts persistent changes at that stage and suggest directions for future research examining naming training effects over longer retention intervals.

The primary goal of the present study was to examine learning mechanisms that drive persistent changes in lexical access. Naming accuracy at Test 1 was the primary outcome measure for this purpose because naming accuracy at the follow-up Test 2 may be influenced by the retrieval practice (without feedback) provided at Test 1. The results of Test 1 are in line with models of learning in lexical access that posit use-dependent change in the strength of lexical connections (Howard et al., 2006; Oppenheim et al., 2010). Specifically, the results support the two-stage, use-dependent learning hypothesis, which states that persistent changes are induced at each stage of lexical access by experiences of mapping from meaning to words (Stage 1) and/or from words to output phonology (Stage 2). By providing opportunities to map from meaning to words, the provision of naming experiences during retrieval practice should strengthen item-specific Stage 1 connections to a greater extent than the exclusive use of repetition during repetition practice. The retrieval practice advantage observed for P1 (with Stage 1 impairment) supports this prediction. Assuming that naming and repetition both provide opportunities to map from words to output phonology, the two training procedures should both strengthen Stage 2 connections. In line with this prediction, P2 (with Stage 2 impairment) did not show a significant advantage of one training approach compared to the other.

The post-hoc analysis for P2 provided further support for our predictions at the level of individual items, revealing a significant interaction between training condition and item type at Test 1. The subset of items that showed evidence of weakened connections at Stage 1 were named with numerically higher accuracy following retrieval practice relative to repetition practice. In contrast, items that showed strong evidence of weakened connections at Stage 2 were named with numerically higher accuracy following repetition practice.

We also included Test 2 at one week post-training to test a longer retention interval that may be informative for the treatment implications of the study. Unlike Test 1, at Test 2 there was no interaction between participants and training condition. Across both participants, retrieval practice was superior to repetition practice; however, this effect was not significant within either of the participants. In addition, in the post-hoc analysis for P2, the interaction between training condition and item type, which was significant at Test 1, was not significant at Test 2. One possible explanation for the different patterns at the two tests is that the retrieval practice provided by Test 1 interacted with the effects of training to influence naming accuracy at Test 2. The retrieval practice literature shows that practice after the first training session can reduce the differences between training conditions, with items assigned to less efficacious training conditions experiencing greater improvement over the subsequent sessions (Rawson & Dunlosky, 2011, 2013; Vaughn et al., 2016). A similar principle may apply here, such that items that received *weaker* benefits from training subsequently received *stronger* benefits from the retrieval attempt at Test 1. For P1, weaker benefits from repetition practice followed by stronger benefits from Test 1 retrieval may account for the absence of a significant retrieval practice advantage at Test 2. For P2, as noted in the Introduction, it is possible that an increased rate of accurate responding during repetition practice relative to retrieval practice could result in greater (not just equal) benefits from repetition practice. Although the difference in Test 1 performance after repetition practice versus retrieval practice was negligible in the primary analyses (see Figure 3a), there was a notable 18% numerical advantage in Test 1 accuracy for repetition practice versus retrieval practice for the Stage-2 items in the post-hoc analysis (see Figure 4a). If we assume weaker benefits from retrieval practice for P2's primary difficulty at Stage 2 followed by stronger benefits from Test 1 retrieval, this may account for the trend towards a retrieval practice advantage at Test 2. This hypothesis could be tested in the future by comparing Test 2 accuracy for trained items included in Test 1 to a set of trained items omitted from Test 1.

It will be particularly important from a clinical perspective to determine whether the pattern of results observed at Test 1 or at Test 2 in the present study is more representative of the long-term effects of retrieval practice versus repetition practice for larger groups of people with aphasia. A recently completed follow-up study (Schuchard & Middleton, under review) sheds light on this question. In this study, we found that items selected to have weakened connections at Stage 1 for each of ten participants with aphasia were named with greater accuracy at retention tests (one day and one week post-training) following retrieval practice relative to repetition practice; in contrast, items selected to have weakened connections at Stage 2 were named with greater accuracy following repetition practice relative to retrieval practice. Similar to the results at Test 1 in the present study, these findings suggest that instances of naming during retrieval practice may be particularly beneficial for strengthening mapping from meaning to words, whereas focusing solely on repetition is at least equally efficacious for strengthening Stage 2 connections. Together, these studies provide preliminary evidence that the underlying cause(s) of an individual's naming impairment is a factor that helps explain, and potentially predict, the outcomes of retrieval practice versus repetition practice. Nevertheless, there are many factors that may contribute to the relative efficacy of these two training methods, and the generalizability of these findings for the highly heterogeneous population of people with aphasia remains an important question for further research.

Another important topic for future investigation is the potential tradeoff between accuracy and effort during these training procedures. Repetition practice usually promotes higher accuracy during training than retrieval practice, as observed for P2, and more research is needed to investigate the extent to which increasing training accuracy benefits post-training performance. In contrast, P1's training accuracy was near ceiling in both conditions. P1's ability to successfully retrieve names during training may have contributed to the strength of the retrieval practice effect on her naming performance at subsequent testing. If this is the case, it may be beneficial to incorporate strategies that promote high accuracy during retrieval practice, such as cueing, as in Middleton et al. (2015), or limiting the number of intervening trials between successive retrieval attempts for an item, as in the present study. On the other hand, challenging training conditions may enhance long-term learning, despite decreased accuracy during training. For neurologically intact adults, retrieval practice effects increase when successful retrieval occurs under more difficult, effortful conditions (Karpicke & Roediger, 2007; Pyc & Rawson, 2009), and even unsuccessful retrieval attempts may enhance learning if they are followed by presentation of the correct response (Kornell, Hays, & Bjork, 2009; Richland, Kornell, & Kao, 2009; Vaughn & Rawson, 2012). These findings are consistent with results from aphasic adults showing an association between greater retention of naming gains and greater effort during training, which was induced by increasing the number of intervening trials between attempts to retrieve an item (Middleton et al., 2016). Further investigation of the effects of effort during training may help optimize difficult-yet-successful processing that promotes long-term retention (Bjork, 1994, 1999).

The present study contributes to an understanding of how self-generated retrieval and oral repetition of words exert change in lexical access. The predictions in this study were extrapolated from emerging models of learning in lexical access because these models are computationally explicit and account for a variety of data across different tasks. However, it will be important in future work to use computational simulations to evaluate the proposed mechanism of change, i.e., that the use of a pathway exerts persistent change in that pathway. In addition, future research should test this account against other possible accounts of naming training effects. For example, hearing and repeating words may strengthen auditory syllable targets, suggesting a possible advantage of repeating auditorily presented words relative to naming for phonological processes that does not necessarily depend on strengthening Stage 2 connections. Specifying the mechanisms of action of specific training experiences may also help identify the necessary and sufficient components of more comprehensive training protocols that have been shown to improve word retrieval in aphasia (e.g., Boyle, 2010; Edmonds, Mammino, & Ojeda, 2014). Hence, further research designed to address these goals will advance the rehabilitation of naming abilities in people with aphasia.

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Appendix A: Pre-training and Post-training Naming Responses for Trained Items

P1

Session	Training Condition	Correct	Phonological errors	Semantic and other errors	No response	Total
Pre-training 1	Repetition practice	27 (25%)	7 (6%)	47 (44%)	27 (25%)	108 (100%)
	Retrieval practice	25 (23%)	1 (1%)	45 (42%)	37 (34%)	108 (100%)
Pre-training 2	Repetition practice	14 (13%)	15 (14%)	42 (39%)	37 (34%)	108 (100%)
	Retrieval practice	13 (12%)	8 (7%)	38 (35%)	49 (45%)	108 (100%)
Test 1	Repetition practice	73 (68%)	4 (4%)	16 (15%)	15 (14%)	108 (100%)
	Retrieval practice	92 (85%)	4 (4%)	6 (6%)	6 (6%)	108 (100%)
Test 2	Repetition practice	64 (59%)	6 (6%)	15 (14%)	23 (21%)	108 (100%)
	Retrieval practice	75 (69%)	4 (4%)	14 (13%)	15 (14%)	108 (100%)

P2

Session	Training Condition	Correct	Phonological errors	Semantic and other errors	No response	Total
Pre-training 1	Repetition practice	30 (28%)	53 (49%)	22 (20%)	3 (3%)	108 (100%)
	Retrieval practice	38 (35%)	46 (43%)	23 (21%)	1 (1%)	108 (100%)
Pre-training 2	Repetition practice	4 (4%)	72 (67%)	31 (29%)	1 (1%)	108 (100%)
	Retrieval practice	3 (3%)	68 (63%)	36 (33%)	1 (1%)	108 (100%)
Test 1	Repetition practice	65 (60%)	40 (37%)	3 (3%)	0 (0%)	108 (100%)
	Retrieval practice	62 (57%)	43 (40%)	3 (3%)	0 (0%)	108 (100%)
Test 2	Repetition practice	57 (53%)	44 (41%)	7 (6%)	0 (0%)	108 (100%)
	Retrieval practice	70 (65%)	26 (24%)	12 (11%)	0 (0%)	108 (100%)

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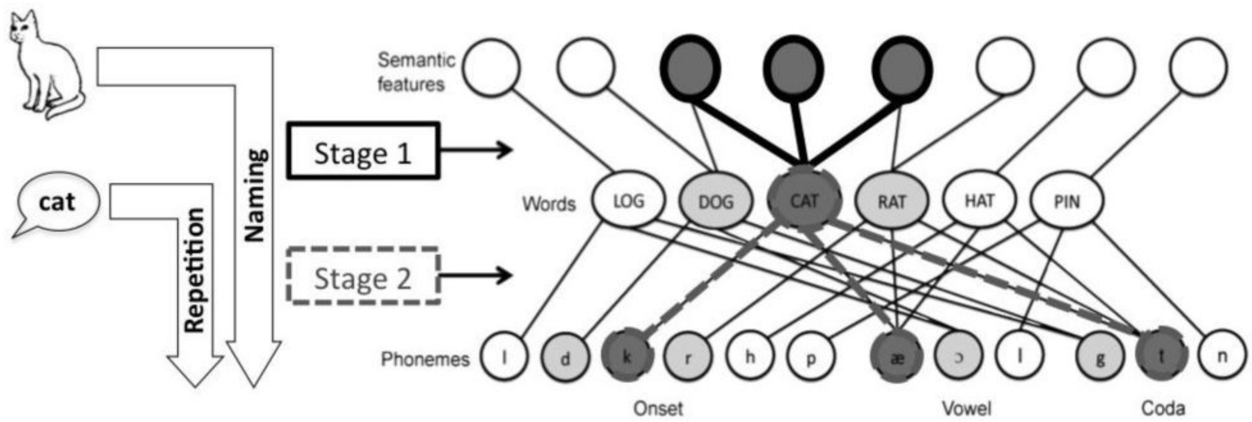

Figure 1.

Two-step interactive model of lexical access and routes of naming versus repetition (lexical route). Modified from figure previously published by the American Psychological Association in Middleton, E. L., Chen, Q., & Verkuilen, J. (2015). Friends and foes in the lexicon: Homophone naming in aphasia. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*(1), p. 86. Reprinted with permission.

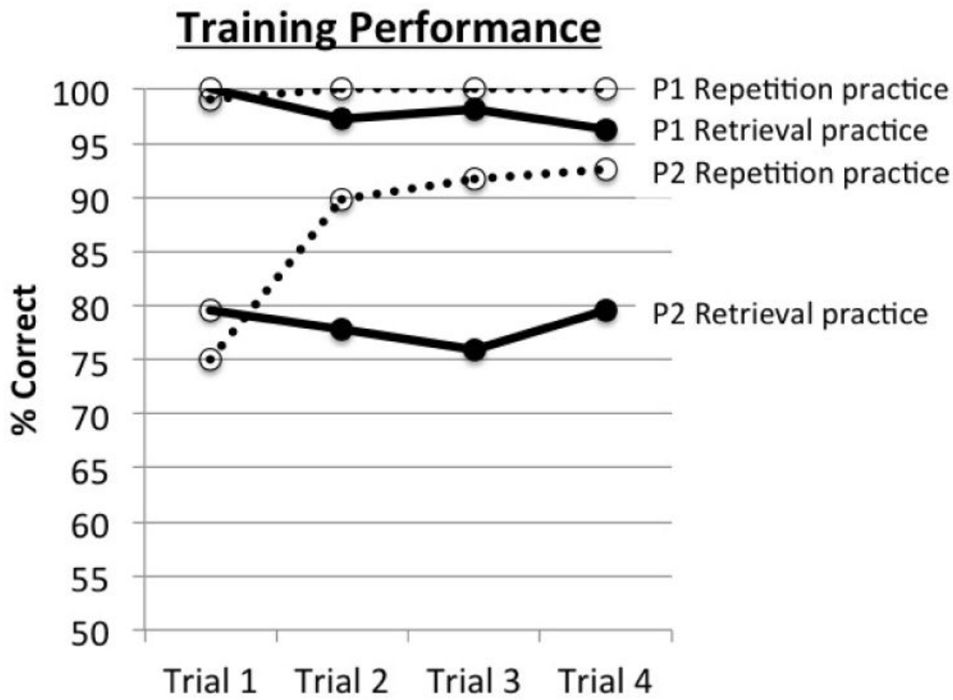

Figure 2.

Response accuracy on the first, second, third, and fourth training trial of each item, averaged across the items in each training condition for P1 and P2. Open circles represent repetition training trials; solid circles represent naming training trials.

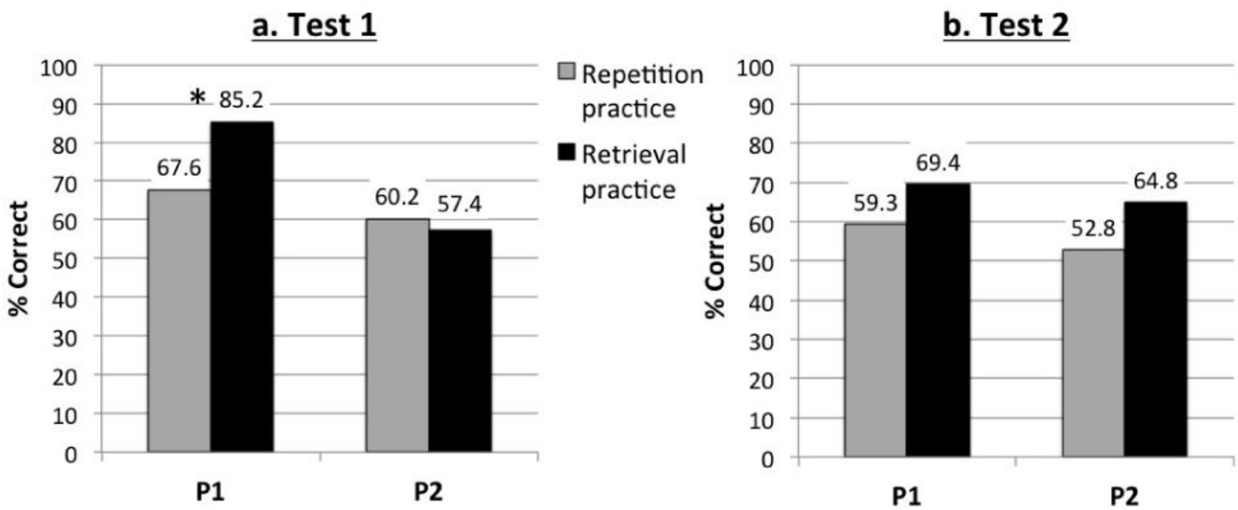

Figure 3.

Average naming accuracy one day post-training (a. Test 1) and one week post-training (b. Test 2).

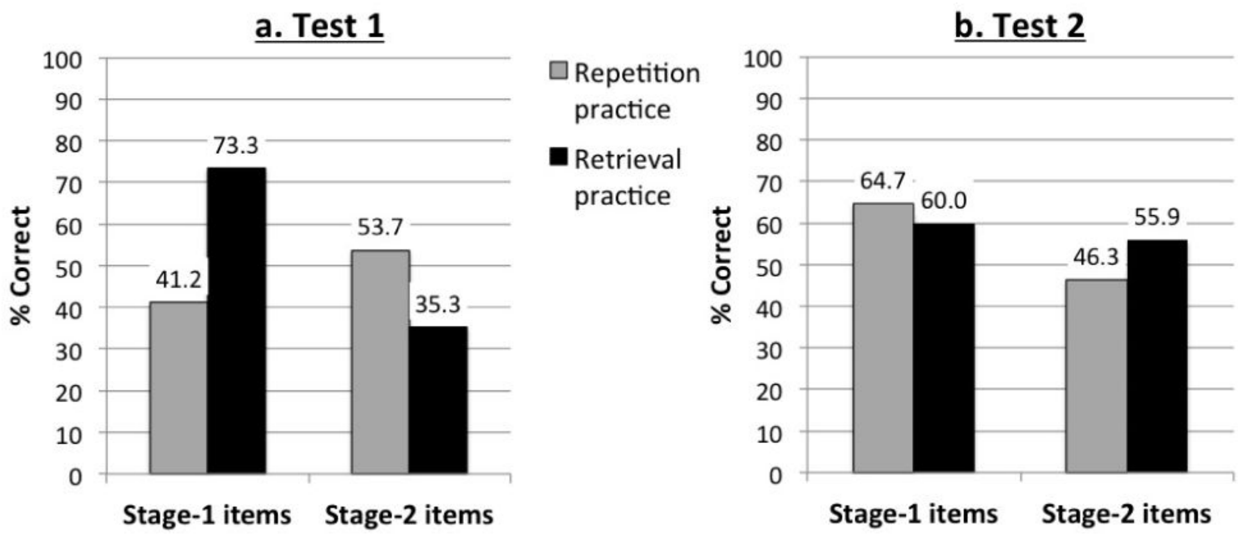

Figure 4.

Average naming accuracy one day post-training (a. Test 1) and one week post-training (b. Test 2) for a subset of P2's items that consistently elicited phonological errors at pre-training (Stage-2 items) or other error types at pre-training (Stage-1 items).

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Table 1

Language Test Scores

Test	Primarily a measure of	P1 score	P2 score	Healthy Adults
Western Aphasia Battery (WAB) Aphasia Quotient	overall severity	88.3	84.5	99.6
WAB Auditory Comprehension	auditory comprehension	9.9	9.7	10
WAB reading subtest	written comprehension	97%	97%	
Philadelphia Name Verification Test	single word comprehension	93%	98%	99%
Pyramids and Palm Trees	nonverbal semantics	88%	98%	98-99%
Camel and Cactus	nonverbal semantics	66%	89%	90%
Synonymy Triplets	verbal semantics	80%	97%	97%
Word Span	short-term memory	3.8	3.6	4.8
WAB Repetition	repetition (single words and phrases)	9.0	7.5	9.9
Philadelphia Repetition Test	repetition (single words)	99%	81%	
Non-Word Repetition Test	repetition (single nonwords)	82%	22%	83%
Philadelphia Naming Test	picture naming			
Correct		77%	64%	97%
Omissions		18%	2%	
Semantic errors		2%	2%	
Phonological errors		2%	28%	
Other errors		1%	4%	
Object Naming Corpus	picture naming			
Correct		66%	54%	
Omissions		19%	3%	
Semantic errors		10%	7%	
Phonological errors		2%	32%	
Other errors		3%	4%	

Note. Language testing included scores from the *Western Aphasia Battery* (WAB; Kertesz, 2007), *Pyramids and Palm Trees Test* (PPT; Howard & Patterson, 1992), *Camel and Cactus Test* (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000), and *Philadelphia Naming Test* (Roach, Schwartz, Martin, Grewal, & Brecher, 1996). Scores for the Object Naming Corpus were obtained from the first administration of the 660-item picture corpus in the item selection phase of the present study. WAB and PPT scores for healthy adults were obtained from normative data reported by Kertesz (2007) and Howard & Patterson (1992), respectively. All other scores for healthy adults were obtained from a group of 20 older adults (mean age = 59) previously tested at Moss Rehabilitation Research Institute.

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Table 2

Characteristics of Trained Items

a.	**Mean *(SD)***			
	Number of Phonemes	**Log Frequency**	**Name Agreement**	**Visual Complexity**
P1				
Repetition practice	5.86 *(2.2)*	0.81 *(0.5)*	0.92 *(0.1)*	2.8 *(0.7)*
Retrieval practice	5.82 *(2.2)*	0.82 *(0.5)*	0.92 *(0.1)*	2.7 *(0.7)*
P2				
Repetition practice	6.00 *(2.1)*	0.82 *(0.5)*	0.92 *(0.1)*	2.6 *(0.7)*
Retrieval practice	6.00 *(2.1)*	0.82 *(0.5)*	0.92 *(0.1)*	2.6 *(0.8)*

b.	**Pre-training Naming Responses**				
	Correct	**Omissions**	**Semantic Errors**	**Phonological Errors**	**Other Errors**
P1					
Repetition practice	19%	44%	20%	10%	7%
Retrieval practice	18%	49%	23%	4%	6%
P2					
Repetition practice	16%	8%	12%	58%	6%
Retrieval practice	19%	2%	17%	53%	9%

Note. Pre-training percentages (b) were calculated by collapsing data across the two administrations of the picture corpus in the item selection phase. No item was produced correctly in both administrations.

Table 3

Regression Models

a. Test 1 Accuracy ~ Condition*Participant

Term	**Estimate**	**SE**	**p-value**
Intercept	0.80	0.11	<0.001
Condition	−0.22	0.11	0.04
Participant	0.44	0.11	<0.001
Condition x Participant	−0.28	0.11	0.01

*b. Test 2 Accuracy ~ Condition*Participant*

Term	**Estimate**	**SE**	**p-value**
Intercept	0.48	0.10	<0.001
Condition	−0.24	0.10	0.02
Participant	0.12	0.10	0.24
Condition x Participant	0.01	0.10	0.89

*c. Test 1 Accuracy ~ Condition*Item Type* (P2 only)

Term	**Estimate**	**SE**	**p-value**
Intercept	−0.05	0.23	0.83
Condition	−0.15	0.23	0.49
Item Type	−0.28	0.23	0.22
Condition x Item Type	−0.53	0.23	0.02

*d. Test 2 Accuracy ~ Condition*Item Type* (P2 only)

Term	**Estimate**	**SE**	**p-value**
Intercept	−0.28	0.22	0.20
Condition	−0.05	0.22	0.83
Item Type	−0.23	0.22	0.29
Condition x Item Type	0.15	0.22	0.50

Note. SE = standard error. Predictor variables were centered (using sum coding).