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Learning to Fail in Aphasia: An Investigation of Error Learning in Naming

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Abstract

Purpose—To determine if the naming impairment in aphasia is influenced by error learning and if error learning is related to type of retrieval strategy.

Method—Nine participants with aphasia and ten neurologically-intact controls named familiar proper noun concepts. When experiencing *tip-of-the-tongue* naming failure (TOT) in an initial TOT-elicitation phase, participants were instructed to adopt phonological or semantic self-cued retrieval strategies. In the error learning manipulation, items evoking TOT states during TOT-elicitation were randomly assigned to a short or long time condition where participants were encouraged to continue to try to retrieve the name for either 20 seconds (short interval) or 60 seconds (long). The incidence of TOT on the same items was measured on a post test after 48-hours. Error learning was defined as a higher rate of recurrent TOTs (TOT at both TOT-elicitation and post test) for items assigned to the long (versus short) time condition.

Results—In the phonological condition, participants with aphasia showed error learning whereas controls showed a pattern opposite to error learning. There was no evidence for error learning in the semantic condition for either group.

Conclusion—Error learning is operative in aphasia, but dependent on the type of strategy employed during naming failure.

Keywords

aphasia; naming; error learning; errorless; cueing; semantic; phonological; tip-of-the-tongue

The most commonly reported problem in aphasia is difficulty retrieving the names of things (i.e., naming impairment) (Goodglass & Kaplan, 1983). Naming impairments are associated with a variety of “errorful” productions, including word substitution errors (“pig” for “cow”), sound errors (“trin” for “train”), exceptionally long production latencies, circumlocutions, and failures to produce any response (i.e., omissions). In research on the treatment of naming impairments in aphasia, interventions are being explored that incorporate *errorless learning* principles that prioritize the elimination of errorful productions during treatment. The development of errorless learning treatments is motivated by the possibility that the act of attempting and failing to produce accurate speech is a learning event in its own right, such that similar errorful productions in the future are made more likely.

The present study investigated whether in individuals with chronic aphasia errorful productions during word retrieval can, through learning, impact the likelihood of future naming failures. Although as noted above, naming impairments manifest in a variety of

behaviors, in the present study error learning was investigated in the context of a particular kind of naming difficulty termed “tip of the tongue” (TOT). A TOT state refers to temporary failed retrieval of a known word. A speaker in a TOT state can often generate partial phonological information, and TOTs are often accompanied by the phenomenology that retrieval seems imminent (i.e., the word is on the “tip of one's tongue”). TOT-like word finding failures are observable in all the classic subtypes of aphasia including Broca's, Wernicke's, conduction aphasia, and anomia (e.g., Badecker, Miozzo, & Zanittini, 1995; Beeson, Holland, & Murray, 1997; Goodglass, Kaplan, & Weintraub, 1976).

Research on the causes of TOT states in typical speakers and speakers with aphasia often references the two main stages of lexical retrieval (Badecker et al., 1995; Burke, Mackay, Worthley & Wade, 1991; Garrett, 1984; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Harley & Bown, 1998; Levelt, Roelofs, & Meyer, 1999; Meyer & Bock, 1992; Vigliocco, Antonini, & Garrett, 1997; Vigliocco, Vinson, Martin, & Garrett, 1999). Stage-1 retrieval involves mapping a semantic concept to a pre-phonological lexical-grammatical representation, or lemma (Kempen & Huijbers, 1983; cf., Lambon Ralph, Sage, & Roberts, 2000; Caramazza, 1997, for different views). The lemma is thought to specify word class information (e.g., noun, verb, or adjective), required syntactic arguments, and grammatical features (e.g., grammatical gender in some languages). Stage-2 involves retrieval of the phonological form (e.g., Dell, 1986; Dell et al., 1997; Foygel & Dell, 2000; Harley, 1993b; Levelt et al., 1999; Rapp & Goldrick, 2000; Roelofs, 1992, 1997; Rumel, Caramazza, Capasso, & Miceli, 2005; and see Schwartz, Dell, Martin, Gahl, & Sobel, 2006 for computational implementations of the framework). TOTs are typically attributed to stage-2 retrieval failure (Bock & Levelt, 1994; Burke et al., 1991; Harley & Bown, 1998; Meyer & Bock, 1992; Miozzo & Caramazza, 1997).

Badecker et al., (1995) studied an Italian speaker with aphasia (Dante), who was prone to TOT-like word-finding difficulties but was otherwise fluent. This individual had good oral reading and repetition, suggesting that his word-finding impairment originated in difficulty retrieving the phonological forms of words rather than impaired post-retrieval phonological sequencing or articulation. In a task involving the naming of objects that lacked natural gender (e.g., *stella*, star-fem), Dante was able to accurately report the meaning and grammatical gender of words that he could not name. His judgments of gender were as accurate for words whose phonological endings were typical of their grammatical gender class as those whose endings were atypical, indicating that he was not accessing phonology covertly to judge gender. This classic study illustrates that TOT states in aphasia can originate in a stage of lexical access that is separate from semantic-syntactic knowledge and is dedicated to the retrieval of phonological form (see Vigliocco et al., 1997; 1999 for related findings).

Recent work with neurologically-intact controls suggests that being in a TOT state may constitute a learning event (Warriner & Humphreys, 2008). To elicit TOTs, Warriner and Humphreys (2008) gave college-aged adults definitions to low frequency words. Participants responded in one of three ways: (1) produced the target (if possible); (2) indicated that they did not know the word that fit the definition; (3) indicated that they knew the word but were experiencing trouble retrieving it. Each TOT state was randomly assigned to a “short” or “long” time condition, where the experimenter gave the participant 10 seconds (short) or 30 seconds (long) to continue to attempt to retrieve the word. In a second session held 48-hours later, participants again attempted to name all items and provided information about the source of their retrieval failures, but without the timing manipulation. The authors hypothesized that the act of being in a TOT is self-reinforcing (i.e., learned), with more learning accruing the longer one remains in a TOT state. In support of this, recurrent TOTs (TOTs at both session 1 and 2) were more likely for items that had been in the long versus

short condition at session 1. The explanation the authors provided was that persisting in TOT states is akin to “spinning one’s tyres in the snow” (p. 540), or learning a dysfunctional pattern of activation in the mapping from lemma to phonology.

If speakers can learn to fail, we might expect to see evidence for error learning in experimental comparisons of “errorless” and “errorful” treatments in aphasia, which have focused primarily on determining the relative efficacy of the two methods in ameliorating naming impairments (Conroy, Sage, & Lambon Ralph, 2009; Fillingham, Sage, & Lambon Ralph, 2005a, 2005b, 2006; McKissock & Ward, 2007). In errorless interventions, errorful productions in naming are systematically avoided whereas under errorful conditions, the elimination of errors is not prioritized. An impetus for investigating errorless learning in aphasia was a series of demonstrations that individuals with amnesia from brain injury can learn errors and show better performance after errorless versus errorful training methods (see Clare and Jones, 2008, and Middleton & Schwartz, 2012, for reviews). This pattern was attributed to the relatively intact implicit memory and dysfunctional explicit memory systems in amnesia: whereas implicit memory enabled the learning of errors (in the errorful condition) and correct responses (in both conditions), impaired explicit memory prevented participants from differentiating errors from correct responses on later assessments (Baddeley & Wilson, 1994).

In aphasia, the canonical errorless intervention for picture naming systematically avoids errorful productions by presenting the object name for repetition in the presence of the depicted object. Under errorful conditions, participants are provided opportunities to retrieve the picture names on their own; this can be with or without retrieval assistance from partial cueing, e.g., first sound/letter. Under errorful naming conditions, error learning may be expected to manifest by similar mechanisms as those suggested by Baddeley and colleagues when memory problems are comorbid with aphasia. Another possibility is that error learning in aphasia would stem from the operation of a normal (but possibly exaggerated) Hebbian learning process (see Fillingham, Hodgson, Sage, & Lambon Ralph, 2003 for discussion). Simple Hebbian learning is a form of associative learning in which stimuli and responses become associated through temporal contiguity alone, irrespective of the correctness of the mapping. Under its operation, producing a response in the presence of a stimulus could strengthen the association as much for incorrect responses as for correct ones.

However, casting doubt on the operation of error learning in aphasia, direct experimental comparisons of errorful and errorless naming treatments have thus far failed to demonstrate convincing benefits of avoiding errors (Conroy et al., 2009; Fillingham et al., 2005a; 2005b; 2006; McKissock & Ward, 2007; see Fillingham et al., 2003; Middleton & Schwartz, 2012 for reviews). Fillingham et al., (2005a, 2005b) found similar performance and retention of treatment gains after errorless and errorful methods, with some suggestion of greater retention after errorful methods reported in Fillingham et al. (2006). In a similar investigation that strictly controlled the amount of feedback between an errorless and errorful method, McKissock and Ward (2007) found no difference between methods for their participants overall. McKissock and Ward’s conclusion was that “it does not matter whether anomic patients are allowed to make errors in picture naming or not.” (p. 355).

Thus, while there is emerging evidence for the learning of errorful naming states in neurologically-intact speakers (Warriner & Humphreys, 2008; see also Humphreys, Menzies, & Lake, 2010), to date there is no direct evidence for error learning in individuals with aphasia. We hypothesized that similar to neurologically-intact speakers, error learning does operate in aphasia, but its effects have been obfuscated in the naming treatment literature due to the operation of different learning principles under errorful and errorless conditions. Specifically, under errorful conditions, a negative impact of error learning on

performance could be offset by a *retrieval practice effect*. It is now well accepted in psychological research on learning and memory that retrieving information from long-term memory *changes* memory, bolstering successful retrieval in the future (i.e., retrieval practice effect; see Roediger & Karpicke, 2006 for review). To illustrate, when initial study of a cue-target pair (e.g., *foot-shoe*) is followed by another study trial versus an opportunity to retrieve the target from the cue (cued-recall, e.g., *foot-s _ _ e*), performance on a later cued-recall test is enhanced having been given an opportunity to practise retrieval of the target compared to more study (Jacoby, 1978). A reason to expect that retrieval practice may impact naming in aphasia is that its effects are robust in a wide variety of verbal learning tasks including learning to produce a second language (e.g., Barcroft, 2007; Royer, 1973). Canonical errorful treatment paradigms in aphasia provide participants regular opportunities to practise retrieving target names from long-term memory, whereas under errorless conditions, repetition training potentially circumvents the requirement of retrieval of target information from long-term memory. Thus, it may be that error learning affects performance in errorful treatments, but its effects are masked because of the countervailing impact of retrieval practice.

The goal of the present work was to investigate the operation of error learning in speakers with aphasia and in neurologically-intact older controls using the basic experimental paradigm of Warriner and Humphreys (2008). Similar to that study, we elicited TOTs in an initial session (hereafter, “TOT-elicitation phase”), and allowed participants to persist in a TOT state for a short or long time, with time (short/long) randomly determined by the experimental software. The same items were presented again in a naming test administered 48-hours after the TOT-elicitation phase (hereafter, “post test”) in order to investigate the likelihood of recurrent TOTs as a function of time. We also instituted a number of changes to the design of Warriner and Humphreys. Firstly, we kept the ratio of long: short conditions at 3:1 but doubled the amount of time allotted. Thus, our participants remained in a TOT state for 60 (long) versus 20 (short) seconds, compared with their 30 vs. 10 sec. Participants with aphasia have longer than normal naming latencies, so we wanted to avoid mistaking instances of slow retrieval for TOT states, which could have been a problem particularly in the short condition had we provided only 10 seconds.

Secondly, we elicited TOTs by having participants name proper noun concepts instead of having them produce words to definitions. Although related verbal elicitation tasks have been used in the past to study TOTs in aphasia (e.g., Badecker et al., 1995), we deemed it preferable to use an elicitation procedure that placed fewer demands on patients' receptive vocabulary, working memory, and discourse/sentence comprehension abilities. Furthermore, proper noun concepts are notorious for eliciting TOTs in everyday life and have been shown to elicit more TOTs than common objects or abstract words, particularly in older adults (Burke et al., 1991; Cohen & Faulkner, 1986; Evrard, 2002; Maylor, 1990; Rastle & Burke, 1996).

A third important change was our operationalization of TOT states. A common practice in TOT research (also adopted by Warriner and Humphreys) is to rely on participants' subjective reports to differentiate naming failures that arise from difficulty retrieving lexical information from those that arise from earlier stages of processing, (i.e., concept recognition). However, evidence suggests that the sensation of TOT can arise from factors unrelated to an activated but inaccessible lexical entry (Metcalf, Schwartz, & Joaquim, 1993; Koriat, 1993; Widner, Otani, Winkelman, 2005; Schwartz, 1998). For example, B. L. Schwartz (1998) found reliable rates of pseudo-TOTs—self-reported TOTs for fabricated general knowledge questions (i.e., questions with no real-world answer). That participants can experience pseudo-TOT states suggests that the reliability of participants to faithfully attribute retrieval failures to a known-but-inaccessible target versus an unknown target is

less than absolute. In this TOT study, we sought to remove the metacognitive burden from participants. To do this, we exposed participants to a large set of proper noun concepts and had them identify items known to them and whose names were familiar. This promoted confidence that naming failures during the TOT-elicitation phase and subsequent post test were in fact TOTs (i.e., involved known concepts with familiar names, where the name was momentarily inaccessible). The operational definition of TOT used throughout the study was retrieval failure for the duration of a trial, except for rare instances when a commission error was produced or when the participant reported they were in fact not familiar with the name or concept.

A final change from Warriner and Humphreys (2008) involved manipulation of the type of retrieval strategy a participant adopted when experiencing TOTs in the TOT-elicitation phase. Warriner and Humphreys employed no such manipulation, so there was no control over the mental processes participants engaged in during the TOT interval, i.e., whether they continued to search their memories throughout the interval and how, if at all, they cued themselves. Here, we instructed participants in the use of semantic and phonological self-cueing strategies and investigated error learning when one or the other strategy was operative. Each participant attempted to name one set of items in the phonological condition, and another set of items in the semantic condition. A third set of items appeared in an “errorless” condition, the purpose of which will be explained shortly.

Recall that TOTs are generally attributed to a failure in stage-2 (phonological) retrieval following successful stage-1 encoding. In Warriner and Humphreys (2008), this motivated a claim that error learning during TOT specifically impacted phonological retrieval. If this is correct, error learning during TOT states should be most apparent when participants use a phonological (rather than a semantic) retrieval strategy. The rationale behind this expectation is that ruminative phonological search will generate or bolster activation of errant or incomplete lemma-phonological mappings. Furthermore, phonologically directed search should be particularly deleterious in the presence of an aphasic naming impairment that features impaired phonological processing. In line with this hypothesis, we selected for the aphasia group individuals in whom phonological access difficulty was a major contributor to naming errors.

What about error learning in the semantic condition? A semantic strategy is expected to focus search on lexical-semantic aspects of a target, yet this retrieval stage is generally not thought to be the source of difficulty during TOT. Thus, we expect that semantic search will neither facilitate nor hinder error learning during TOTs except insofar as it effectively discourages or distracts from phonological search. In that case, error learning may be reduced in the semantic condition, compared to the phonological condition.

To summarize, the primary research questions concerned items that evoked TOTs during the elicitation phase and again during the 48-hour post test: (1) Is the probability of such recurrent TOTs higher for items in the long vs. short time condition (error learning effect)? (2) Is the error learning effect modulated by retrieval strategy condition (error learning by strategy interaction)? (3) Is error learning stronger in participants with aphasia compared to controls (error learning by group interaction)?

Viewed from the perspective of naming treatment, the TOT-elicitation phase constitutes 1-trial errorful treatment of target words (i.e., naming attempt followed by repetition feedback; see Methods). As 1-trial naming treatments have been known to produce short-term improvement (e.g., Howard, Patterson, Franklin, Orchard-Lisle & Morton, 1985), a secondary aim of this study was to contrast the treatment outcome, measured by post test accuracy, for items trained under errorful compared to errorless treatment. To do this, we

added an errorless condition where participants simply repeated the names of items (i.e., naming errors were systematically avoided). Assuming measurable error learning in the TOT-elicitation conditions, the straightforward prediction is for higher post test accuracy in the errorless condition. However, as discussed earlier, in addition to inviting errors, the errorful (i.e., TOT) conditions also provide opportunities for successful retrieval practice. This could balance the negative effects of error learning, conceivably tipping the scale in favor of errorful treatment. As the relative strength of these two factors is unknown (particularly in the current experiment), we had no strong predictions for this errorful-errorless comparison.

Methods

Overview

In an initial *item selection screen*, a large set of unique entities (e.g., famous people, places, etc.) was presented to assess naming and to identify each participant's "personal item set" (i.e., items that the participant recognized and whose names were familiar). An individual's personal item set was distributed into three conditions of the TOT-elicitation phase: phonological, semantic, and errorless (see Figure 1). In the phonological condition, participants employed phonological self-cueing during TOT states; in the semantic condition, they employed semantic self-cueing; and during the errorless condition they were not allowed to experience TOTs but instead simply repeated the name of the item after hearing it spoken. Each TOT-elicitation session was followed by a post test on the same items after 48-hours.

Experimental investigations of TOTs are necessarily opportunistic, taking advantage of events that occur sporadically and unpredictably. With this in mind, we designed the study to maximize the number of items per condition per participant. First, we started with a very large set (600) of proper noun depictions from which individual participants' personal item sets were derived. Secondly, we required a minimum number of TOTs in the item selection screen for an individual's continued participation in the study. Thirdly, we selected a group of participants with aphasia that were relatively homogeneous in terms of their language and cognitive impairments. We expected this to increase the likelihood that individual response to the manipulations would conform to a uniform pattern, which would help bolster power by decreasing variability. This procedure did result in a different number of observations per condition across participants. However, this is quite common in psychological research on speech errors where typically some portion of responses are unanalyzable with respects to key dependent measures.

Participants

Participants were recruited from Moss Rehabilitation Research Institute's pool of research volunteers and gave informed consent under a protocol approved by the Institutional Review Board of Einstein Healthcare Network. Participants were reimbursed \$15 for each hour of participation. Results will be presented from nine participants (three female) with aphasia (hereafter, aphasia group). One additional participant was enrolled but subsequently excluded because of failure to meet the requisite minimum number of TOTs on the item selection task (i.e., 125 or approximately 20% of the 600-item set). The mean education level of the aphasia group was 15.6 years ($SD = 2.7$, range 12–21 years) with a mean age of 56 ($SD = 14$; range 33–73).

Results will be presented from ten neurologically-intact older adults (controls), of whom five were female. An additional five controls were enrolled but subsequently excluded. One participant was excluded on account of failure to follow instructions. Four were excluded

because they failed to meet the requisite minimum number of TOTs on the item selection task; (note, due to experimenter error, participant C7 fell somewhat short of the minimum but was included). The mean education level of the control group was 13.6 years ($SD = 2$; range 12–16) with a mean age of 66 ($SD = 7$; range 55–76). The greater age of controls approached significance [$t(17) = 1.98, p = .06$]; we revisit this in the discussion. Education was not different between the aphasia group and the control group ($p = .09$). None of the controls had a self-reported history of neurological/psychiatric illness or brain injury and all scored at or above the traditional cutoff for cognitive dysfunction (O'Bryant, Humphreys, Smith, Ivnik & Graff-Radford et al., 2008) on the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975; $M = 28, SD = 2$, range 24–30). An additional six older adults provided normative judgments to assist materials preparation.

The participants with aphasia were right-handed with chronic aphasia secondary to left-hemisphere stroke, with the exception of P1, whose clinical scan showed bilateral damage. Table 1 shows their performance on various cognitive and language tasks, relative to a reference sample comprised of 102 individuals with diverse aphasia presentations whose behavioral data was available in the Moss Aphasia Psycholinguistics Project (www.mapdpd.org/) and for whom there was also CT or MRI confirmation of left hemisphere stroke. Compared to the reference sample, the study participants demonstrated mild to moderate aphasia, performing at or above average on measures of word comprehension (*Picture-name verification test*: Does the word match the picture?; Mirman, Strauss, Brecher, Walker & Sobel et al., 2010; *Synonymy triplets*: Pick two of three words that are synonyms.; Martin, Schwartz, & Kohen, 2006) and nonverbal semantic comprehension (*Camel and Cactus Test*, picture version: Does camel go best with cactus, tree, sunflower, rose?; Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000). Participant P3 was an exception, showing lower performance on the *Camel and Cactus Test* relative to the reference sample mean and the other aphasia participants. Otherwise, this individual's profile was very similar to other members of the aphasia group.

The numbering of the aphasia participants in the tables and throughout reflects their accuracy on the *Philadelphia Naming Test* (Roach, Schwartz, Martin, Grewal, & Brecher, 1996). PNT accuracy and error scores are presented in Table 2, where it can be seen that P1 had the lowest correct score and P9 the highest. In all cases, the naming impairment was in mild-moderate range. Phonologically related errors (formal errors and phonologically related nonwords) comprised an average of 35% of their errors (range 9% to 88%). In the absence of core semantic deficits, omissions and circumlocutions may constitute further evidence of phonological retrieval difficulty. The sum of omissions/circumlocutions and phonologically-related errors accounted for a majority (59%) of the groups' naming errors (range 31% to 92%). Most of the remaining errors on the PNT were semantically related to targets (see Semantic and Mixed columns in Table 2); across the group, these accounted for 4% to 55% of total errors. In individuals without core semantic deficits, production of semantically related errors in naming is likely to signal disruption in the mapping from concept to lemma during stage-1 retrieval (Dell et al., 1997; Schwartz et al., 2006), although such errors have been known to arise from phonological output problems (Caramazza & Hillis, 1990). Thus, our sample of participants with aphasia is best described as having phonologically-based naming problems with variable degrees of additional stage-1 retrieval difficulty.

Materials

Pictures for 600 proper names were taken from the internet. The 600-item picture corpus included famous people (e.g., film stars, politicians, historical figures), places, fictional characters (e.g., Mickey Mouse) and films with iconic movie posters. Ratings from six older

adults who did not participate in the main study confirmed these items would be generally familiar to people in the age range of our participants.

Procedure

Item Selection Screen—In session(s) prior to the experiment, participants were administered an item selection screen, where the 600 pictured items were presented for a naming attempt. The participant was provided 30 seconds to retrieve the name followed by a prompt for recognition (“Do you recognize this/him/her? 1=yes, 2=not sure, 3=no”) and a prompt for familiarity (“Is the name you're searching for familiar? How familiar? 1=very, 2=somewhat, 3=not very”). The stimulus set for each participant was individualized: an individual's *personal item set* was composed of all items they judged were familiar and that they recognized (items a participant gave a 2 or 1 for both the familiarity and recognition judgments). The personal item sets across participants contained mostly items that were highly recognizable and familiar to them. Across participants, an average of 95% of items in the personal item sets were awarded a “1” for both familiarity and recognition.

TOT-Elicitation Phase—For each participant, items from their personal item set were divided among the semantic, phonological, and errorless conditions, matching the sets for familiarity, recognizability, and naming performance. Because the manipulations of retrieval strategy and time in TOT were of greatest interest, the phonological and semantic conditions were each assigned 42% of an individual's personal item set. The remainder (16%) was assigned to the errorless condition.

During TOT-elicitation in the semantic and phonological conditions, type of retrieval strategy was structured by a series of prompts. The phonological prompts were the same across the different categories of items (e.g., films, people) and are listed in Figure 1. The semantic prompts changed slightly between the different categories of items. For example, for films, the prompts were What can you tell me about this movie?/What is it about?/Do you know who was in it, or who directed it?/Have you seen it, and if so, with whom? Figure 1 lists the prompts in the semantic condition for famous people.

TOT-elicitation in the phonological and semantic conditions began with random assignment of items to *strategy induction* and *experimental* trials. Strategy induction trials were used to teach the participant the strategy when experiencing TOT. Such trials appeared periodically throughout the TOT-elicitation session with the aim of establishing a strategy “mental set” that would carry over to the experimental trials. On induction trials, the (semantic or phonological) prompts were visually displayed, and the experimenter used the prompts in a serial fashion to structure a participant's search for up to 1 minute (or less, if the TOT-state resolved prior to one minute).

The experimental trials were of primary importance, as the time factor (short/long time in TOT) was manipulated on these trials only. On experimental trials the prompts were no longer displayed, but participants were instructed to continue to use the strategy when experiencing TOT. Assignment of a trial to the short or long condition was randomly determined by the experimental software and signaled covertly to the experimenter. If the participant was experiencing a TOT, the experimenter engaged the participant in the strategy and ended search 20 seconds (short time condition) or 60 seconds (long) from the onset of the trial by presenting the answer for repetition. On any trial (strategy induction or experimental), if the TOT was resolved before the deadline, or if the participant provided a confident wrong response, the trial was terminated with presentation/repetition of the name.

Semantic and phonological TOT-elicitation sessions commenced with 20 strategy induction trials, followed by 20 experimental trials, followed by 5 more strategy induction trials (to

further reinforce the strategy), then 20 more experimental trials, then 5 strategy induction trials and so on until the set of items assigned to that condition was exhausted.

In the errorless condition, all trials proceeded in a uniform way: the presentation of the picture was accompanied by a spoken and written model of the name; and the participant repeated the name twice in immediate succession. This procedure equated the number of productions in the errorless condition with the maximum possible rate of accurate productions of items during TOT-elicitation in the retrieval strategy conditions. Semantic, phonological, and errorless conditions were administered in separate weeks with the order of conditions counterbalanced within each group of participants. Experimental procedures were presented on a Dell computer using EPrime Software (2.0).

Post Test—In the post test, all items trained in a prior session were presented for naming in random order. The participant was provided up to 30 seconds to attempt to retrieve the name. No specific strategy for retrieval was suggested or encouraged. The target lag between TOT-elicitation and post test sessions was two days, but there was some variability in actual lag due to scheduling difficulties. Lag did not differ across conditions ($p = .34$), but it was reliably shorter for the control group than the aphasia group [$F(1, 17) = 4.79$, $MS = 3.75$, $p = .04$]. We will return to this in the discussion.

Data Coding & Analysis

Participants' verbal responses were digitally recorded and transcribed by research assistants trained in IPA. Transcribed responses were coded independently by two research assistants naïve to the hypotheses. Inter-rater reliability was high (92% for the aphasia group; 94% for controls). Discrepancies in coding were resolved through discussion between three research assistants trained in the coding scheme.

Responses collected in the TOT-elicitation and post test sessions were coded into four categories: *correct*=name was produced correctly at any point during the trial; *partial TOT*=at least one syllable was produced; *full TOT*=less than one syllable was produced; *don't know*=participant confidently produced the wrong name, or indicated to the experimenter that the item was not recognized or familiar. The *don't know* category was rare, and these trials were excluded from the main analyses. Lenient scoring for accuracy (credit for 1-phoneme off) was applied for the one participant (P8) who had (mild) speech apraxia. African American vernacular variations in phonology were accepted as well.

To evaluate the presence of error learning and its relation to retrieval strategy, the analysis focused on items assigned to experimental trials during TOT-elicitation in the semantic and phonological conditions. A subset of TOTs were resolved prior to the (short or long) deadline. The items that were not resolved prior to deadline (including partial and full TOTs) are of primary interest, and we refer to these as *potential recurrent TOTs*. The key measure is the proportion of these that elicit a TOT on the post test (*recurrent TOTs* or *rTOTs*). This is the *rTOT proportion* shown in (1).

$$rTOT \text{ proportion} = \frac{\text{recurrent TOTs}}{\text{potential recurrent TOTs}} \quad (1)$$

The error learning analysis involved a three-way mixed factor ANOVA applied to the rTOT proportion measure, with Group entered as a between participants factor and Time (short, long) and Strategy (phonological, semantic) as within-participants factors. This was followed by separate repeated measures ANOVAs for each strategy condition, with the dependent variable again rTOT and the factors Group (between participants) and Time (within participants). In subsequent planned pairwise tests, the effect of time (long, short)

was compared within each group using paired, two-tailed t-tests. An alpha level of $p = .05$ was used for all statistical tests. Effect sizes were calculated for statistically significant tests using partial eta squared (η^2) for the ANOVAs and Cohen's d for the t-tests. TOT proportions, raw counts of experimental trials, potential recurrent TOTs, and recurrent TOTs for both participant groups are reported in Supplemental Table 1 (see Supplemental Materials).

As noted, a secondary question was whether the presence of error learning in one or both TOT-elicitation conditions was associated with lower overall accuracy at post test, relative to the errorless condition. To anticipate the results, as error learning was apparent only in the phonological condition, this analysis involved a two-way mixed factor ANOVA applied to post test accuracy with Group entered as a between participants factor and Condition (phonological, errorless) entered as a within participants factor.

Results

Recurrent TOT proportions

In the 3-way ANOVA on rTOT proportion, there was no overall error learning effect (no main effect of Time, $p = .97$), and no Strategy by Time interaction ($p = .32$). However, there was a reliable three-way interaction of Time, Strategy and Group [$F(1, 17) = 9.00$, $MS = .06$, $p < .01$, $\eta^2 = .35$]. To unpack this interaction, we analyzed the effects of Time and Group for semantic and phonological conditions, separately.

We consider first the semantic condition: In the aphasia group, the mean rTOT proportion in the short and long conditions was, respectively, $.54$ ($SD = .22$) and $.51$ ($SD = .19$); in controls, the respective means were $.32$ ($SD = .22$) and $.38$ ($SD = .23$). In the 2-way ANOVA for the semantic condition, there were no main effects and no interaction of Group and Time (all $ps > .05$). These data were not analyzed further.

Turning to the phonological condition: For the aphasia group, the mean rTOT proportion in the short and long conditions was, respectively, $.45$ ($SD = .22$) and $.50$ ($SD = .24$). For the control group, the respective means were $.44$ ($SD = .20$) and $.35$ ($SD = .22$). The ANOVA yielded no main effect of Time or Group; but the interaction of Time and Group was reliable [$F(1, 17) = 9.45$, $MS = .05$, $p < .01$, $\eta^2 = .36$]. Planned pairwise comparisons confirmed that in the aphasia group, the rTOT proportion was reliably higher in the long condition compared with short [$t(8) = 2.30$, $p = .05$, Cohen's $d = .77$]. This is consistent with our predictions and indicative of error learning. In the control group, the rTOT proportion was reliably *lower* in the long condition compared with short [$t(9) = 2.35$, $p = .04$, Cohen's $d = .74$]. This is a pattern opposite the error learning effect reported by Warriner and Humphreys (2008).

Seven of nine participants in the aphasia group (P1, P2, P3, P4, P5, P6, P7) showed a numerical effect consistent with the phonological condition group means (rTOT proportion long > rTOT proportion short; see Supplemental Table 1). In controls too, the group-level pattern (rTOT proportion long time condition < rTOT proportion short time condition) was consistent at the individual level, with 8 of 10 participants showing the pattern.

Post test accuracy

Mean post test accuracy for the aphasia group in the phonological condition was $.62$ ($SD = .24$) and in the errorless condition, $.60$ ($SD = .25$). For the control group, mean accuracy in the phonological and errorless conditions was, respectively, $.80$ ($SD = .15$) and $.79$ ($SD = .15$). The ANOVA yielded no main effect of Condition ($p = .35$), a marginal main effect of Group [$F(1, 17) = 3.99$, $MS = .31$, $p = .06$], and no interaction ($p = .66$).

Discussion

The goal of the present work was to diagnose the operation of error learning in aphasic naming. People with aphasia and neurologically-intact older adults attempted to name a large set of familiar unique entities. The amount of time they were permitted to remain in a TOT state was manipulated along with retrieval strategy, where participants attempted to generate semantic, or alternatively phonological features/associates of a target when experiencing TOT. We found that time in TOT was related to the error learning measure, but only in the phonological strategy condition. Moreover, in that condition, the two groups had opposite responses to the time-in-TOT manipulation. In the aphasia group, longer time spent in TOT resulted in a higher proportion of rTOT. This is indicative of error learning. In the control group, longer time in TOT resulted in a lower proportion of rTOT. This is contrary to error learning and runs counter to Warriner and Humphreys (2008), where the manipulation of time spent in TOT yielded evidence of error learning in young adults. As group means can sometimes be misleading, particularly where the samples are small and neurological participants are involved, it is noteworthy that the group-level effects we observed did reflect the numerical patterns present in a majority of participants in each group. In the subsequent sections, we discuss the aphasia results first, followed by the results for controls.

We predicted *a priori* that error learning would be most apparent in the phonological condition. This prediction was based on the claim by Warriner and Humphreys (2008) that what is learned during unresolved TOT states is an incorrect or incomplete activation pattern projected across lemma-phonology connections. We expected that a strategy focusing lexical search on the recovery of phonology might reinforce such errant activation patterns (e.g., by generating more, or more persistent, non-target phonemes).

As noted, we obtained the predicted error learning in the phonological condition only in the group with aphasia. We selected these participants with the expectation that their phonological-level impairments would promote more opportunities for errant phonological activation patterns to arise and, with added time spent in TOT, grow in strength. The results support this reasoning. Important to note, the participants with aphasia were recruited because of *a priori* expectations regarding a link between impaired phonological processing and error learning during TOT. It remains to be seen whether error learning operates in speakers with aphasia with different profiles of naming impairment, and how its operation relates to the type of error studied.

In the phonological condition, we interpret the aphasia group's response to the time-in-TOT manipulation as evidence for error learning. However, there is a potential confound to consider, namely that this error learning effect reflects item-selection bias introduced by the timing manipulation. The argument runs as follows: assume that items lie on a continuum of difficulty, with variable TOT resolution times. Because of random assignment, the distributions in the two time conditions would be similar. Recall that the main dependent variable involved a tabulation of "potential recurrent TOTs" (i.e., items that persisted in TOT past the 20 or 60 second deadline during TOT-elicitation). In the long time condition, items with resolution times in the 20–60 second interval would be resolved during TOT-elicitation; thus, potential recurrent TOTs in this condition would comprise only items that require more than 60 seconds for resolution. In the short time condition, potential recurrent TOTs would include all items that require at least 20 seconds for resolution. At post test, harder items (those that require >60 seconds) would be more likely to lead to a recurrent TOT than easier items, creating an illusory error learning effect.

The selection bias account makes a concrete prediction: if, during the TOT-elicitation phase, the 20–60 second time window that was available for the long- but not short-condition items had in fact been used to resolve some TOTs, then the long condition should be associated with higher accuracy during the TOT-elicitation phase. However, there was no such pattern: in the phonological strategy condition, accuracy in this phase was similar in the two time conditions ($M = .48$, short; $M = .47$, long). Furthermore, if the timing manipulation introduced an item selection bias, it is not clear by this account why its workings would not have manifested in a comparable error learning effect for controls and in the semantic condition, as well.

The findings we obtained for controls were frankly surprising. Based on the results of Warriner and Humphreys (2008) and the hypotheses outlined in the introduction, we expected to observe error learning minimally in the phonological condition. Instead, in that condition, controls' mean rTOT proportion was lower in the long condition. Why were we unable to replicate Warriner and Humphreys? Our study differed from theirs in a number of ways: we studied older rather than younger adults; our short and long time conditions were lengthened with respect to theirs; we focused on proper noun names instead of common names; we guided participants in the use of a self-cueing strategy. We are disinclined to attribute the different pattern of results to our use of a phonological strategy, as it proved to be important to obtaining error learning in the aphasia group. Instead, we view the difference in the timing manipulation between the two studies as potentially relevant. In Warriner and Humphreys, the 30 second (long) condition was associated with a higher rTOT proportion than the 10 second (short) condition. In our study, the 20 second (short) condition was associated with a higher rTOT proportion than the 60 second (long) condition. Potentially reconciling the two patterns across the two studies, it may be that in controls, error learning occurs sometime between 10 and 30 seconds; after 30 seconds of TOT, processes may come into play that somehow mitigate the error learning effect. Further research is needed to investigate how time in TOT and other factors influence error learning in typical speakers, as well as speakers with aphasia.

An additional question is why the control group showed a pattern opposite that of the aphasia group with respects to error learning in the phonological condition. The issue of age surfaces again here, as the controls were on average 10 years older than the participants with aphasia, a difference that approached significance. Older individuals are more likely to experience phonological retrieval failures leading to TOT states (Burke et al., 1991), but under the present hypothesis worse phonological retrieval is expected to promote error learning in the phonological condition. So the age difference does not seem like a plausible reason for the absence of error learning in controls. A second difference between the groups is that the average lag between TOT-elicitation and post test was shorter for controls. However, assuming that error learning, like other types of learning, dissipates with time, a shorter interval should be associated with more—not less—error learning. Whatever the explanation, the evidence indicates that under a phonological retrieval strategy, the aphasia group experienced error learning while the control group did not. In line with the original hypothesis, we take this as confirmation that it is the vulnerability to phonological retrieval failure in the aphasia group—coupled with a search strategy that exploits such vulnerability—that made them, and not the controls, prone to error learning.

The analysis on post test accuracy revealed no effect of Condition and no Condition by Group interaction. Thus, although the aphasia group showed error learning in the phonological condition (and controls showed the opposite pattern), there was no evidence that the opportunity to err or the actual learning of errors (in the aphasia group) disadvantaged post test performance, relative to the errorless condition. While several studies have shown that errorful methods of treating naming impairments do not produce

worse outcomes than errorless methods (e.g., Fillingham et al., 2005a; 2005b; 2006) this is the first time such a comparison has been made in the context of an actual demonstration of error learning. In keeping with what was said in the Introduction, it may be that the negative impact of error learning in the phonological condition was offset by benefits of retrieval practice. However, as with all efforts to explain null results, this interpretation is speculative. With just a single trial of treatment (errorful or errorless) per item, the impact of error learning and/or the benefit of retrieval practice may simply have been too small to exert a measurable impact on post test accuracy.

In summary, this work provides original evidence that error learning is operative in aphasia, and can affect the likelihood of a repeated error days after the learning has occurred. The error learning effect was obtained with only one episode of potential error learning per item. Although overall accuracy in this study was not affected by error learning, multiple opportunities for prolonged error states on items is not uncommon in traditional speech therapy settings. Under these conditions, the impact of error learning on treatment outcome may be of some consequence. This possibility, coupled with the finding that error learning effects can span days, underscores the need for further study of error learning in experimental designs that more closely approximate clinical treatments and that weigh the consequences of error learning against potential benefits of retrieval practice.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Schematic of procedure. See text for details.

Table 1

Characteristics of the Participants with Aphasia.

Participant	Onset ^a	Type	WABQ ^b	WDR ^c	z	NWDR ^d	z	CCT ^e	z	PNVT ^f	z	SYN ^g	z
P1	33	A	89	74	-0.78	32	-0.61	78	0.21	76	-0.69	93	0.81
P2	19	A	83	N/A		N/A		81	0.41	N/A		77	-0.14
P3	49	A	88	98	0.78	80	1.24	39	-2.38	89	0.14	83	0.22
P4	41	C	83	91	0.33	37	-0.41	84	0.60	88	0.08	80	0.04
P5	30	A	74	95	0.59	42	-0.22	77	0.14	95	0.52	57	-1.32
P6	32	A	92	96	0.65	52	0.16	88	0.87	99	0.77	100	1.23
P7	370	A	90	95	0.59	83	1.35	88	0.87	96	0.58	90	0.63
P8	73	A	92	97	0.72	85	1.43	94	1.27	99	0.77	90	0.63
P9	23	C	79	77	-0.59	32	-0.61	81	0.41	85	-0.11	97	1.05

Note: z = z scores calculated from the mean and standard deviation of a large diverse group of individuals (N = 102) diagnosed with aphasia resulting from left-hemisphere stroke.

N/A = test score not available. C = conduction. A = anomic.

^aMonths post onset.

^bWestern Aphasia Battery (WAB) quotient (Kertesz, 1982).

^cSingle word repetition test (in percentages).

^dNonword repetition test (in percentages).

^eCamel and Cactus Test (Bozeat et al., 2000), a linguistic test of semantic comprehension (in percentages).

^fPicture-word verification test (in percentages; Mirman et al., 2010).

^gSynonymy triplets (nouns and verbs; Martin et al., 2006).

Table 2
Philadelphia Naming Test Performance of the Participants with Aphasia, Including Error Proportions.

Participant	Correct	S	M	% (S,M)	F	NW	O/C	%(F,NW,O/C)	U	PP	O
P1	0.72	0.00	0.01	0.04	0.10	0.11	0.02	0.86	0.00	0.02	0.01
P2	0.73	0.03	0.03	0.23	0.05	0.06	0.03	0.51	0.03	0.00	0.04
P3	0.75	0.04	0.05	0.35	0.01	0.03	0.07	0.47	0.01	0.03	0.01
P4	0.81	0.03	0.01	0.21	0.01	0.01	0.11	0.68	0.01	0.01	0.01
P5	0.83	0.05	0.03	0.48	0.00	0.03	0.02	0.31	0.00	0.01	0.02
P6	0.86	0.01	0.00	0.08	0.04	0.08	0.01	0.92	0.00	0.00	0.00
P7	0.87	0.05	0.02	0.55	0.01	0.01	0.03	0.36	0.00	0.01	0.01
P8	0.93	0.02	0.00	0.33	0.00	0.01	0.02	0.50	0.00	0.01	0.00
P9	0.94	0.01	0.01	0.20	0.00	0.02	0.02	0.70	0.00	0.01	0.00

Note: Philadelphia Naming Test: Roach et al. (1996).

S = semantic error; M = mixed error; % (S,M) = total percent of semantic and mixed errors out of all errors; F = formal error; NW = nonword error; O/C = omissions/circumlocutions; % (F,NW,O/C) = total percent of formal, nonword errors, omissions/circumlocutions out of all errors; U = unrelated error; PP = picture part error; O = other, which was predominantly perseverations or phonological errors on whole word substitution errors that were semantically and phonologically related to the target.