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Errorless Learning in Cognitive Rehabilitation: A Critical Review

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Abstract

Cognitive rehabilitation research is increasingly exploring *errorless learning* interventions, which prioritize the avoidance of errors during treatment. The errorless learning approach was originally developed for patients with severe anterograde amnesia, who were deemed to be at particular risk for error learning. Errorless learning has since been investigated in other memory-impaired populations (e.g., Alzheimer's disease) and acquired aphasia. In typical errorless training, target information is presented to the participant for study or immediate reproduction, a method that prevents participants from attempting to retrieve target information from long-term memory (i.e., *retrieval practice*). However, assuring error elimination by preventing difficult (and error-permitting) retrieval practice is a potential major drawback of the errorless approach. This review begins with discussion of research in the psychology of learning and memory that demonstrates the importance of difficult (and potentially errorful) retrieval practice for robust learning and prolonged performance gains. We then review treatment research comparing errorless and errorful methods in amnesia and aphasia, where only the latter provides (difficult) retrieval practice opportunities. In each clinical domain we find the advantage of the errorless approach is limited and may be offset by the therapeutic potential of retrieval practice. Gaps in current knowledge are identified that preclude strong conclusions regarding a preference for errorless treatments over methods that prioritize difficult retrieval practice. We offer recommendations for future research aimed at a strong test of errorless learning treatments, which involves direct comparison with methods where retrieval practice effects are maximized for long-term gains.

Keywords

errorless; errorful; retrieval practice; testing; spacing; aphasia; amnesia

Introduction

A recent trend in cognitive rehabilitation, which is particularly prominent in treatment research on aphasia and amnesia, is exploration of the errorless learning approach. In errorless treatments, the priority is to prevent participants from making errors during treatment. Most commonly this is achieved by preventing patient attempts at retrieving target responses from long-term memory; instead, on each trial a target response is provided (e.g., for study) to bolster its association with the appropriate stimulus. For example, during standard errorless (EL) treatment of naming impairments in aphasia (Conroy, Sage, & Lambon Ralph, 2009b; Fillingham, Sage, & Lambon Ralph, 2005a, 2005b, 2006; McKissock & Ward, 2007), the target name for a depicted object is provided on each training trial (the word is seen/heard for repetition) in a manner that preempts attempts at retrieving the name from long-term lexical memory. In contrast, in more traditional *errorful* (EF) treatments, retrieval attempts come to the forefront and the elimination of errors is not

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prioritized. For example, in EF treatments of naming impairments, an object is presented and participants attempt to retrieve the name, creating an opportunity for either retrieval success or failure.

The errorless learning approach in cognitive rehabilitation originated in the amnesia literature as an application of established principles of learning and memory. The basic notion was that responses experienced during training become primed in memory by means of implicit learning mechanisms that continue to operate in amnesia. Such learning pertains to errors and correct responses alike. In neurologically-intact individuals, conscious or explicit memory of having made an error minimizes the impact of error learning. However, the deficit in explicit recall in people with amnesia eliminates this counterweight to error learning and renders a person with amnesia more vulnerable to its impact (Anderson & Craik, 2006; Baddeley & Wilson, 1994; Page, Wilson, Shiel, Carter, & Norris, 2000; cf., Hunkin, Squires, Parkin, & Tidy, 1998, Tailby & Haslam, 2003 for a different view). It follows that for people with amnesia, at least, the optimal rehabilitation strategy should be one that encourages learning while eliminating or at least minimizing retrieval errors (i.e., EL treatment).

To properly evaluate this proposition--and the effectiveness of EL more generally--requires a good understanding of what errorless learning is not (i.e., what is lost when one prioritizes the elimination of retrieval errors). The most obvious missing ingredient is opportunity to engage in difficult (hence error-prone) acts of retrieval. Yet psychological research in learning and memory identifies this factor, which we will refer to as *retrieval practice*, as perhaps the most important determinant of successful learning (see Roediger & Karpicke, 2006a, for review).

Empirical demonstrations to this effect begin with an initial study period, giving participants an opportunity to commit target information to memory. This is followed by further study opportunities or in lieu of more study, opportunities to engage in (practice) retrieving the target information. The superior learning from retrieval practice or *testing* memory versus restudying target material (i.e., testing effect) has been established in a great variety of populations and in numerous learning domains. Furthermore, research suggests that retrieval practice effects are most robust and long-lasting when retrieval is effortful yet successful (i.e., when retrieval is *desirably difficult*; Bjork, 1994). A well-researched means to manipulate retrieval difficulty is through the schedule with which items are repeatedly practiced. Numerous studies have demonstrated that spacing retrieval practice over time outperforms non-spaced (massed) schedules of learning, particularly when critical performance measures are administered after a delay (i.e., spacing effect; see Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006 for review).

Our goal in this paper is to evaluate the importance of avoiding errors in cognitive interventions, particularly when weighed against the therapeutic potential of effortful retrieval practice. We begin with an overview of psychological research that demonstrates the powerful learning associated with retrieval practice and related phenomena. There follows a critical evaluation of the literature on errorless learning in amnesia, highlighting findings that identify limits on the scope of effects. The special case of error learning in speech is then considered, followed by a review of errorless learning research in aphasia. In reviewing the errorless learning literature in amnesia and aphasia, we devote particular attention to the outcomes of controlled comparisons of EL versus EF treatments. In the end, we conclude that though error learning may be a factor that influences treatment outcomes in these rehabilitative domains, its importance might be offset by benefits to performance from retrieval practice under EF training conditions, especially if these are maximized by appropriate schedules of learning. The sections on errorless learning in amnesia and aphasia

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are each concluded with suggestions for important future research on errorless learning, retrieval practice, and schedules of learning.

Retrieval Practice in Learning and Memory

A well-accepted principle in research on learning and memory is that retrieving information from long-term memory (retrieval practice) is a learning event in its own right. The literature on *testing effects* has explored how retrieval practice impacts learning when participants are given multiple attempts to retrieve the same item across a series of tests. In an early systematic exploration of testing effects, Tulving (1967) tracked the rate of learning a list of words across multiple cycles of different sequences of study (S) and test (T) events. In the SSST (repeated study) condition, in each of six cycles the entire word list was studied three times followed by one recall test. In the STST (standard study-recall) condition, the entire word list was studied, followed by a test, then study, then test. Interestingly, Tulving found that the STST condition resulted in similar performance as the SSST condition on the session-final test, even though participants studied the list 6 more times in the SSST condition. Using the same paradigm but with a final recall test held after 1-week, Karpicke and Roediger (2007b) found 68% recall in the STST condition compared to 57% recall in the SSST condition. In a variant of this design (Karpicke and Roediger, 2008), final performance after 1-week for training involving tests (80%) greatly outperformed training involving more study (36%), demonstrating a robust long-term advantage for training involving retrieval practice.

The superiority of testing over more study has been reported in additional studies (Cull, 2000; Roediger & Karpicke, 2006b; Thompson, Winger, & Bartlin, 1978; Wheeler, Ewers, & Buonanno, 2003), with mounting evidence suggesting the advantage for testing is at least partly due to its role in reducing forgetting. From an immediate (5-min post training) to a delayed memory probe (48-hours), Thompson, et al. (1978) found the percentage of information loss was only 13% in a repeated test condition (STTT) versus an alarming 56% for repeated study (SSSS).[1] Using a similar paradigm but with a retention interval of 1-week, Wheeler et al., (2003) found that the percentage of information loss after repeated study was 75% compared to roughly 30% after repeated test (calculated from their Figure 2; p. 576). Further evidence suggests that forgetting is inversely related to the number of tests during learning. Wheeler and Roediger (1992) reported 46% information loss when study was followed by no tests versus 13% information loss when study was followed by three opportunities (without feedback) to attempt to recall studied material. In addition to its importance for committing lists of words to memory, retrieval practice effects have been established for a great variety of types of verbal learning including learning paired-associates (i.e., associating words to other words, e.g., dog-spoon; Allen, Mahler, & Estes, 1969; Carrier & Pashler, 1992; Izawa, 1970; Jacoby, 1978), face-name associations (Carpenter & DeLosh, 2005), pictures (Wheeler & Roediger, 1992), and text materials (Kang, McDermott, & Roediger, 2007; Roediger & Karpicke, 2006b).

Interestingly, other work on testing suggests its impact is not wholly contingent on successful retrieval and that tests which lead to failure still promote learning (Izawa, 1970; Kornell, Hays, & Bjork, 2009; Richland, Kornell, & Kao, 2009). To illustrate, one method used by Kornell et al. (2009) to ensure retrieval practice failure during learning involved fictional questions with no real-world answer (e.g., “Who shot a fig out of a tree with a crossbow in the 11th century?). Questions were either presented alone to enable a (failed) retrieval attempt, after which the answer was presented for study; or the question and answer

[1]Drawing from Roediger & Karpicke (2006a), information loss is calculated as the difference between performance on immediate and delayed tests divided by performance on the immediate test.

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was presented for study, with no initial retrieval attempt. Performance on a final cued recall test held at least 38-hours after study (Experiment 5) was higher after having attempted (and failed) to retrieve target responses during learning versus not having experienced tests during learning. This suggests that the benefits of testing go beyond the learning that occurs from successful retrieval. That is, the sheer exercise of testing oneself, and then being given the answer, leads to better recall of target information.

One might question whether these effects actually depend on retrieval at all, as opposed to what happens on the heels of a retrieval attempt. For example, perhaps participants process the target information more deeply and elaboratively when they have just retrieved it, or heard it as a form of post-retrieval feedback. Although plausible in light of the known benefits of deep encoding (Craik & Lockhart, 1972; Lockhart & Craik, 1990), this alone cannot explain retrieval practice effects. First, evidence suggests that training involving retrieval practice substantially outperforms training involving elaborative encoding on final memory measures (Karpicke & Blunt, 2011). Furthermore, retrieval practice effects are not reducible to elaborative encoding of feedback because the power of testing memory is well established even in the absence of feedback (e.g., Thompson et al., 1978; Roediger & Karpicke, 2006b; Wheeler & Roediger, 1992; Wheeler et al., 2003). Thus, the power of testing memory likely originates from at least two distinct sources: (1) retrieving information from long-term memory changes memory in a way that bolsters the likelihood of successful retrieval in the future; (2) retrieval failure can lead to deeper encoding of target information subsequently provided as feedback, compared to a situation where no test is administered. It is the first of these—retrieval—that is most important for achieving robust learning.

In sum, work on testing effects in non-clinical populations appears to be at odds with the majority of errorless learning frameworks in cognitive rehabilitation, where the avoidance of retrieval errors is prioritized. Key findings in our next topic of discussion also run counter to the core feature of errorless learning treatments. Specifically, research on testing in the context of schedules of learning has revealed that experimental manipulations that increase the difficulty of retrieval practice (and likelihood of retrieval errors during training) produce the best long-term performance benefits.

Schedules of Learning

The literature on schedules of learning spans over a century of research and has attracted numerous comprehensive reviews and meta-analyses (for most recent of each, respectively, see Delaney, Verkoeijen, & Spirgel, 2010 and Cepeda et al., 2006). Our review of this literature will be selective, with a focus on studies that are likely to have relevance for cognitive rehabilitation.

The most robust phenomenon in the literature on schedules of learning is the *spacing effect*: when items are studied or tested in multiple sessions distributed across time (>1-sec) or across intervening items (in *distributed schedules*), the learning and retention of information is superior than in *massed schedules* (i.e., studying an item once for a prolonged period of time, or taking multiple tests in immediate succession). In their meta-analysis of studies investigating spacing effects in the learning of verbal materials (e.g., facts, word lists, picture names), Cepeda et al. (2006) found that of 271 comparisons between spaced schedules and massed only 12 showed no difference or worse performance from spacing.

The meta-analysis in Cepeda et al. (2006) included studies that investigated the effects of spacing on both repeated test trials and repeated study trials. Specific to paradigms that employ tests during training, the magnitude and retention of learning after repeated tests is closely tied to the schedule with which tests are administered, with distributed schedules

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almost always outperforming massed (Balota, Duchek, Sergent-Marshall, & Roediger, 2006; Carpenter & DeLosh, 2005; Cull, Shaughnessy, & Zechmeister, 1996; Cull, 2000; Logan & Balota, 2008; Landauer & Bjork, 1978). To illustrate, pioneering work by Landauer and Bjork (1978) on the learning of verbal materials (e.g., face-name pairs) compared fixed-distributed schedules (e.g., an item was tested every 5 items, or 5-5-5), expanding-distributed schedules (e.g., an item was tested with 1, then 4, then 10 intervening items, or 1-4-10), and massed schedules (e.g., 0-0-0). On final recall performance assessed at the end of the session, expanding outperformed the fixed schedule, which in turn outperformed the massed schedule.

The standard testing effect (i.e., the boost to long-term performance from training involving multiple tests versus multiple study trials) is most robust when tests are administered in a distributed fashion. For example, in training face-name pairs, Carpenter and DeLosh (2005) found reliable testing effects after distributed but not massed schedules. Discussed in greater detail below, findings like this are indicative of an important link between retrieval difficulty and learning (Finley, Benjamin, Hays, Bjork, & Kornell, 2011; Karpicke & Roediger, 2007a; Pashler, Zarow, & Triplett, 2003; Pyc & Rawson, 2009). When tests are presented in massed fashion after an initial study episode, the requirement for long-term memory retrieval is minimized by the availability of the information in short-term or working memory; hence, testing effects under massed schedules are notably absent.

As noted earlier, Landauer and Bjork (1978) found superior performance after expanding- compared to a fixed-distributed schedule on a test administered at the end of the training session. However, the potential superiority of expanding over fixed schedules has proven to be a complicated issue, as recent studies have demonstrated equal or superior performance with fixed schedules (Balota et al., 2006; Carpenter & DeLosh, 2005; Cull, 2000; Logan & Balota, 2008; Karpicke & Roediger, 2007a), particularly when memory is assessed after a delay. To illustrate, Logan and Balota (2008) found that performance (cued-recall of a paired-associate) measured during and immediately after the learning phase was better for expanding schedules, whereas on a final test held one day later, the advantage switched to fixed. Also in paired-associate learning, Karpicke and Roediger (2007a) found that though there was an advantage for expanding schedules throughout learning and on tests held 10-min after learning, fixed schedules outperformed expanding when the final test was administered after a 2-day lag. Further experimentation by these authors (revisited in greater detail below) revealed the performance differences between schedules at different time points was related to the role of retrieval difficulty and its impact on the retention of learning.

A meta-analysis of relevant studies (Cepeda et al., 2006) found overall very similar performance for expanding and fixed schedules across a range of retention intervals, which complicates claims about the superiority of fixed schedules on long-term measures. However, Cepeda et al. noted large between-study variability, which may have been due to variation in the inclusion of feedback across studies. When tests are administered according to a fixed schedule, if the initial lag is too long or the initial study exposure too brief, retrieval may fail on the initial test, and tests thereafter without feedback. Here, the comparison may favor expanding over fixed because expanding schedules generally have a shorter initial lag. However, the introduction of feedback can counter such potential limitations of fixed interval schedules. In summary, fixed schedules may be preferable to expanding schedules, particularly when feedback is provided and key performance measures involve retention over a delay.

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Retrieval Difficulty and Long-Term Retention of Learning

The debate over expanding versus fixed schedules led to key insights regarding retrieval difficulty and learning. As trends emerged showing that the learning conditions that led to the highest short-term performance (e.g., expanding and massed schedules) were associated with inferior retention, researchers began to explore the relationship between difficulty during training and long-term performance (Karpicke & Roediger, 2007a; Pashler et al., 2003; Pyc & Rawson, 2009; see Schmidt & Bjork, 1992, for discussion). What has emerged is that retrieval difficulty is good for later performance, and its effects appear to operate independently of type of schedule. To illustrate, Karpicke and Roediger (2007a; Experiment 3) manipulated type of schedule (fixed/expanding) as well as the number of intervening items (lag) between initial study and first test (0 items or 5 items), with final performance measured after delays of 10 min or 2 days. At 10 min, there was no difference as a function of lag or schedule. However, after 2 days, performance was better in the 5-item compared to the 0-item lag condition, with no difference between fixed or expanding schedules. Reaction time analyses, which revealed slowest retrieval times on the lag-5 initial tests, confirmed the importance of retrieval difficulty during learning for long-term performance (see Pyc & Rawson, 2009 for similar results).

The benefit of retrieval difficulty to retention is demonstrable even when increases in retrieval difficulty lead to high rates of errors during training. To illustrate, in Pashler et al. (2003), on Day 1, participants studied a series of Eskimo-English word pairs, and after two intervening items attempted to generate the English word given the Eskimo cue (i.e., Test 1). The experimental manipulation involved the lag (in terms of number of intervening items) at which they encountered a repeat test (Test 2) after Test 1. See Figure 1, where the abscissa corresponds to lag between Test 1 and Test 2, and the ordinate denotes cued-recall performance. As one might expect, performance on Test 1 was flat, as lag was held constant between initial study and Test 1. Another predictable outcome was that as the lag between Test 1 and Test 2 increased, performance on Test 2 decreased. However, the remarkable finding was that on final performance on a test held the next day (Day 2 test), performance *increased* as a function of lag between Test 1 and Test 2. Pashler et al. found similar results with and without the provision of feedback, as well as when the lag between tests was increased up to 96 items and final performance was measured after a week rather than one day. Their results clearly demonstrate that retrieval difficulty (even when associated with a preponderance of errors during training) has powerful effects on long-term performance.

Researchers in this field have long acknowledged that there are upper bounds to retrieval difficulty. Bjork (1994) was referring to such limitations when he coined the term “desirable difficulties,” denoting that optimal learning arises when retrieval is maximally difficult, yet successful. After a point, however, retrieval is expected to become so difficult that retrieval failure rate during training translates into diminishing returns on final performance measures. Later we provide recommendations for how the paradigm employed by Pashler et al. could be used to develop training methods that exploit desirable difficulty for a clinical population.

To summarize, the literature on testing and spacing has revealed a number of key insights into the nature of learning and memory that run counter to most errorless learning treatments in cognitive rehabilitation. First, the most powerful learning is obtained when training involves opportunities for individuals to practice retrieving target information from long-term memory. This is at odds with the majority of errorless learning paradigms where retrieval attempts are largely preempted or discouraged. Second, though conditions that increase difficult retrieval (and errors) may decrease performance during training, such conditions promote the best long-term retention of training effects. Errorless learning treatments largely fail to capitalize on this powerful learning principle, as they prioritize

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errorless performance during training. In the sections that follow, we consider how this tension plays out in research on errorless learning in clinical populations.

Errorless Learning in Amnesia

Most neuropsychological studies of errorless learning have focused on individuals with amnesia resulting from acquired brain injury or neurodegenerative conditions, including dementia of the Alzheimer type (DAT). Amnesia, in this context, refers to an impairment within long-term, explicit, episodic memory that impedes the conscious recall of new information. As many studies have investigated errorless learning in amnesia, we refer readers to a more comprehensive review by Clare and Jones (2008). For our purposes, we provide a selective review focused on the question of whether methods that prioritize the elimination of errors (i.e., EL treatments) yield better outcomes with this population than methods that encourage difficult (and error-prone) retrieval practice (i.e., EF treatments).

Before beginning, a note on terminology: Throughout this paper, we use the term *standard EL treatment* to refer to the most common form of errorless learning, where the target response is provided on training trials and retrieval practice is pre-empted -- a training method that is essentially errorless. We then contrast standard EL with EF treatments, including in the latter category vanishing cues treatment. In vanishing cues therapy, retrieval errors are minimized on early trials, but opportunities for retrieval practice (and errors) are introduced on later trials as cueing support is systematically reduced. According to some investigators, the strong cuing support in early trials qualifies vanishing cues as a “errorless” or “error-reducing” form of intervention (e.g., Komatsu, Mimura, Kato, Makamatsu, & Kashima, 2000). We take a different view: because vanishing cues can lead to a substantial number of errors (see Komatsu et al., 2000; Riley & Heaton, 2000) and it prioritizes retrieval practice, here, we treat it as an EF method. We have taken pains to note all cases in which our re-classification of techniques leads to conclusions different from the original authors.

Baddeley and Wilson carried out the earliest comparisons of EL and EF treatments in amnesia (Baddeley & Wilson, 1994; Wilson, Baddeley, Evans, & Shiel, 1994). In Baddeley and Wilson (1994) people with severe amnesia from acquired brain injury and neurologically intact controls studied words under standard EL conditions (e.g., I'm thinking of a word AR_ _ _ _ and it's ARTIST) or standard EF (trial-and-error) conditions. On EF trials, participants were encouraged to generate several possible completions (e.g., ARCHES) during training before being given the correct answer. Whereas the neurologically intact groups showed no strong advantage for either method, the patients showed uniformly better performance on same-session stem completion tests after EL versus EF training (see Hunkin et al., 1998; Page et al., 2006 for similar results). Baddeley and Wilson attributed the EL advantage to the relatively intact implicit memory and dysfunctional explicit memory systems in amnesia: implicit memory enables the learning of errors and correct training responses, but impaired explicit memory prevents patients from differentiating errors from correct responses at final test (see Anderson & Craik, 2006; Hunkin et al., 1998; Page et al., 2006; Tailby & Haslam, 2003 for debate and supporting evidence). Also in patients with severe amnesia, Wilson et al. (1994) found that standard EL training was superior to standard EF for a variety of tasks including the learning of names, programming an electronic memory aid, and in a memory-impaired individual who also had visual agnosia, learning object names.

These early studies focused on individuals with severe amnesia. In more recent studies, a number of qualifications as to the superiority of EL techniques in memory-impaired populations has emerged, with caveats having to do with how memory is probed, the severity of memory impairment, and the longevity of treatment effects. Evans, Wilson,

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Schuri, Andrade, and Baddeley et al., (2000) carried out a series of experiments in which face-name learning was trained in patients with moderate to severe amnesia from acquired brain injury. There was a tendency for standard EL treatment to outperform standard EF treatment when the final test involved onset-cued naming (a task that arguably can be completed by the operation of implicit memory) but not when the final test was free recall (an explicit recall task) (cf., Hunkin et al., 1998 for different results). Others of Evans et al.'s (2000) experiments compared EL and EF methods for training a sequence of steps in programming an electronic organizer or navigating a route. In these experiments, the trend was for trial-and-error training to equal or outperform EL treatment at final test (see Kessels, van Loon, & Wester, 2007 for similar results in route learning with severe amnesic Korsakoff patients; cf., Lloyd, Riley, & Powell, 2009, for different results). The upshot of this work seems to be that the superiority of EL over EF learning is linked to how memory is probed at final test, with EL learning more likely to show an advantage on tests that can be completed by primed representations in implicit memory rather than requiring explicit recall of trained items or sequences. Tasks that require explicit memory may benefit more from techniques that prioritize retrieval practice opportunities. Riley, Sotiriou, and Jaspal (2004) found support for this conclusion in a study they conducted, also involving amnesia from acquired brain injury. They found that vanishing cues training (as noted by these authors, more error prone and likely to incorporate retrieval practice than standard EL treatment) led to better performance on explicit memory measures (e.g., free recall) than standard EL treatment. In turn, standard EL learning produced better perceptual identification, a task that is sensitive to primed representations in implicit memory.[2] Thus, EL might not be the preferred approach when the target skill for rehabilitation requires the explicit recall of learned information (see Hogan and Kintsch, 1971 for converging evidence with healthy controls).

As researchers have extended investigations of EL and EF methods to individuals with DAT, the case for prioritizing the avoidance of retrieval errors has further unraveled. Metzler-Baddeley and Snowden (2005) trained four patients with DAT who ranged in the severity of their memory impairment and dementia. None of those tested showed a reliable difference between standard EL and EF training in the subsequent recall of names for objects and people, although at a group level, EL training was statistically superior to EF. Haslam, Moss, & Hodder, (2010) reported statistically equivalent effectiveness in vanishing cues and standard EL training in face-name learning across a large group of individuals with DAT. With a similar task and population, Bier, Van der Linden, Gagnon, Desrosiers, and Adam et al. (2008) found training methods that emphasized retrieval from long-term memory (i.e., vanishing cues, spaced retrieval) tended to outperform standard EL on delayed memory measures. Furthermore, among all training methods studied, spaced retrieval enabled the greatest number of patients to demonstrate equivalent learning as neurologically-intact controls. Thus, there is no consistent advantage for methods that prioritize the avoidance of retrieval errors compared to methods that incorporate regular retrieval practice in individuals with memory impairment from DAT.

Researchers in this domain have begun to recognize potential limitations of standard EL treatment, among them that opportunities to engage in effortful processing (e.g., elaborative encoding or retrieval practice) during training are minimal. Building on a paradigm pioneered by Komatsu et al. (2000), Dunn and Clare (2007) investigated the role of effort and error in training face-name associations in patients with early-stage dementia. They compared the standard EL method (classified as errorless/effortless), vanishing cues

[2]In Riley et al.'s interpretation, their results reflected the operation of transfer appropriate processing. In this view, both standard EL treatment and vanishing cues are effective for implicit learning, but the match between study and test format is an important predictor of which type of training will emerge as superior for a specific test format.

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(classified as errorless/effortful; but see earlier note on terminology), accumulating cues (errorful/effortful), and face-name matching (errorful/effortless). Along with vanishing cues, the accumulating cues procedure provided opportunities for retrieval practice: on each trial the initial letter was supplied and letters were added as needed until the patient could retrieve the correct response. Accumulating cueing produced numerically the highest performance across tests of free recall, cued recall and recognition of novel face-name associations, and on a test of free recall of famous names. Accumulating and vanishing cues reliably outperformed the other methods on cued-recall for the novel stimuli. Thus, the types of training that prioritized retrieval practice—accumulating cues and vanishing cues—tended to produce superior treatment gains. Furthermore, it was the more errorful (hence, effortful) of these (i.e., accumulating cues) that was associated with the most robust learning.

Other researchers have attempted to develop methods that are errorless but that incorporate retrieval practice, reflecting a concern that standard errorless learning is limited in its impact because it eschews retrieval practice. A study by Tailby and Haslam (2003) encouraged successful retrieval practice in patients with severe to mild memory impairment from acquired brain injury. The standard EL method of fragment completion (e.g., “I'm thinking of a 5-letter word that begins with BR and it's bread”) and standard EF method (e.g., “I'm thinking of a 5-letter word that begins with BR”) were compared to a retrieval condition where the stem was supplemented with a definition (e.g., “I'm thinking of a five letter word that begins with BR and it's a food made from flour, yeast, liquid and is baked…”). Tailby and Halsam deemed the retrieval condition “errorless” because participants tended to not make errors during training. The retrieval condition outperformed standard EL, which outperformed standard EF on later cued-recall tests (see Lubinsky, Rich, & Anderson, 2009 for similar results in individuals with mild cognitive impairment). Laffan, Metzler-Baddeley, Walker, and Jones (2010) investigated the impact of retrieval practice in relearning famous peoples' names (i.e., names the participant had known prior to onset) in memory-impaired individuals with mild to moderate DAT. Training involving a retrieval attempt followed by assisted retrieval from cued naming led to greater treatment gains than training where the target was simply provided after a failed retrieval attempt. Note, participants were instructed to refrain from overtly responding in the assisted retrieval condition when they were unsure of an answer, which promoted errorless learning. Further work is needed to determine whether the errorless aspect of such frameworks is important, or whether the most important feature of such approaches is that they promote successful retrieval practice. In sum, there are numerous indications in variants of both EL and EF paradigms that promoting successful retrieval from long-term memory bolsters learning in mild to moderate memory-impaired individuals.

Finally, while differences in the persistence of EL and EF treatment effects has not been systematically examined in this literature, there are indications that treatment gains from EF methods may be more enduring. In an investigation of patients with a range of memory impairments, Squiers, Hunkin, and Parkin (1997) reported a benefit for standard EL learning of distantly associated word pairs (e.g., SALAD-COLD) over EF learning on an immediate test of cued-recall (e.g., SALAD- ______), but this difference disappeared after a 1 hour delay (Experiment 1). In a second experiment, EL learning outperformed EF on an immediate cued-recall test and again after 30 minutes. However, performance significantly decreased from the immediate to delayed test after EL learning, and not after EF learning. In another study, in which patients with differing degrees of memory impairment were tested on repeated stem-completion tests across a 48-hour delay, Hunkin et al., (1998) also reported significant forgetting on items trained with EL methods and not with EF methods. Future research in this area should evaluate how information acquired during EL or EF training degrades over extended periods of time, in order to develop a more complete picture

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of the relative merits of EL treatments and methods that regularly encourage retrieval practice (EF).

To summarize: comparisons between EL and EF methods have produced variable results, depending on the type of patient and the training task. In patients with mild to moderate memory impairment, such as those in the early stages of DAT, EF methods can produce comparable (or better) learning, relative to EL methods (Bier et al., 2008; Dunn & Clare, 2007; Haslam et al., 2010; Metzler-Baddeley & Snowden, 2005; Riley et al., 2004). Avoidance of errors during training may take on greater importance in individuals with severe amnesia (Baddeley &Wilson, 1994; Hunkin et al., 1998; Page et al., 2006; Riley & Heaton, 2000; Squires et al., 1997; Wilson et al., 1994). However, even in these cases, the superiority of standard EL treatment does not consistently extend to tasks that go beyond implicit learning (e.g., the explicit recall of verbal information; Evans et al., 2000; Riley et al., 2004). Moreover, the negative consequences of error learning may have been exaggerated in the earlier amnesia literature because under standard EF conditions, patients are encouraged to guess and produce errors when otherwise they might have refrained from responding. Furthermore, a growing number of studies show that memory-impaired individuals benefit from regular opportunities to attempt to retrieve target information from long-term memory (Dunn & Clare, 2007; Laffan et al., 2010; Tailby & Haslam, 2003), a feature that is absent in standard EL treatment. Finally, we lack strong evidence regarding the persistence of treatment effects in EL versus EF methods in this literature, with some indication that EF methods may be more robust against forgetting (Hunkin et al., 1998; Squiers et al., 1997).

Retrieval Practice and Spacing Effects in Amnesia

A number of studies provide converging evidence to the patterns identified here that individuals with amnesia benefit from retrieval practice, particularly when its effects are enhanced by manipulations that increase retrieval difficulty (i.e., spaced schedules of learning). Early work on schedules in DAT and other forms of dementia investigated the efficacy of treatments involving *adjusted expanding test schedules* (e.g., Abrahams and Camp, 1993; Brush & Camp, 1998; Camp, 1989; Camp, Foss, O'Hanlon, & Stevens, 1996). In an adjusted expanding schedule, errors that occur are corrected immediately and followed by a reduced interval before retesting; successes are followed by an increased interval. Camp and colleagues demonstrated successes using such a schedule for training a variety skills. However, because of lack of appropriate controls, this work falls short of establishing the efficacy of an adjusted expanding schedule compared to other schedules or treatments.

Subsequent studies have established the functional relevance of retrieval practice in memory-impaired populations, particularly when its effects are enhanced by efficacious schedules of learning. Sumowksi, Chiaravalloti, and DeLuca (2010) found superior performance for spaced testing over spaced study in memory impairment from multiple sclerosis, demonstrating the importance of retrieval practice in this population. Though in earlier work, Hochhalter, Overmier, Gasper, Bakke, and Holub (2005) found no difference in DAT between five different test schedules including adjusted expanded, massed, random, fixed distributed, and expanding distributed schedules, work which followed demonstrated robust effects of spacing in memory impairment. Balota et al., (2006) found in two studies (one with feedback and one without) an advantage for fixed-distributed and expanding test schedules over massed test schedules for patients with DAT. Finally, in a direct comparison between training involving spaced retrieval practice and standard errorless learning, Haslam, Hodder, and Yates, (2011) found in memory-impaired individuals (from either acquired brain injury or dementia) that an expanding test schedule reliably outperformed errorless learning on final performance measures.

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Errorless Learning in Amnesia: Synthesis and Future Directions

The studies described in the prior section are timely and relevant to research on errorless learning in amnesia in a number of key ways. They demonstrate that individuals with memory impairment benefit from treatments involving retrieval practice and from schedules of testing that increase retrieval difficulty (i.e., spaced schedules). Furthermore, they offer perspective on the scope of error learning—training involving massed schedules (e.g., Balota et al., 2006), study conditions (Sumowski et al., 2010), and errorless learning (Halsam et al., 2011) lead to very few (or no) errors during training, yet these types of training were associated with the poorest performance on final measures. This is commensurate with a key principle of the testing and spacing literature with neurologically-intact controls, where treatments that lead to the highest performance (and fewest errors) during training often rate the most poorly on delayed measures. Finally, these studies suggest that the benefits to performance from retrieval practice (when its effects are maximized via schedules of learning) far outweigh any potential detriment from error learning, at least in the specific patient populations studied.

One recommendation for future evaluations of the value of errorless learning in amnesia is to compare errorless treatments to more realistic errorful treatments. For example, starting with Baddeley and Wilson (1994) and largely adopted throughout the literature, in standard errorful treatment (at least on initial trials), if a patient generates the correct response (e.g., SPADE for SP_ _ _), the intended target is switched (e.g., “Sorry, the correct word is SPIRE”), a procedure that ensures errorful treatments are artificially errorful. Such procedures would not realistically be adopted by clinicians, and the importance of evaluating their efficacy relative to other interventions is questionable. More useful comparisons would involve evaluating the efficacy of errorless procedures relative to error-permitting treatments where retrieval success is possible (or perhaps facilitated, e.g., with an accumulating cues procedure; see Dunn & Clare, 2007 for example) on every trial. Indeed, when errorful interventions are designed in ways that are principled with respects to clinical goals, they outperform error-reducing treatments in memory-impaired populations (Balota et al., 2006; Haslam et al., 2011; Sumowski et al., 2011).

An issue worthy of brief mention is that the debate over the merits of errorless learning could benefit from a standardization in classifying methods as errorless/errorful. For example, in contrast to some researchers, here we classified vanishing cues treatment as an errorful method because it can (but does not always) lead to substantial rates of errors. Ultimately, the value of errorless learning approaches will be more accurately described if empirical rates of errors—rather than subjective determinations—are used to firmly establish a treatment as errorless or errorful.

Future work on errorless learning should involve “strong tests” of its merits, meaning comparison to training that not only prioritizes retrieval practice but endeavors to maximize its effects through the manipulation of desirable difficulty. As an illustration, consider the Pashler et al., (2003) paradigm discussed earlier, where lag between an initial test event and a subsequent test event during training was systematically manipulated (i.e., training lag). To revisit the main finding, as training lag increased, performance on the second test during training decreased, but final test performance assessed the next day *increased* with training lag. This reflects the importance of difficult retrieval—as retrieval difficulty during training increases, it increasingly bolsters delayed retrieval success. Although the studies in Pashler et al., did not identify the limits of this effect, one presumes that increases in training lag would eventually be associated with decreases in performance on final measures (i.e., when retrieval success during training becomes too infrequent). The Pashler method could be adapted to diagnose an “optimal” lag where retrieval during training is hard but still largely successful, as indicated by the lag associated with the highest performance at final test. This

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optimal training lag could then be used to set the interval between repeated testing of individual items in an "optimized" fixed-distributed schedule of testing. In order to evaluate the relative efficacy of such an optimized schedule of retrieval practice against errorless learning, errorless training events (e.g., study) could be presented in the same schedule as test events, providing a strong evaluation of the importance of error-elimination in memory rehabilitation.

Another domain within cognitive rehabilitation where the errorless learning approach has been well studied is in aphasia – language impairment resulting from left hemisphere damage. Since aphasia is not typically associated with the amnesic symptom complex that is commonly thought to confer vulnerability to error learning, it is useful to explore the motivation for this line of inquiry. We therefore precede the review of studies of errorless learning in aphasia with a brief discussion of incremental language learning and recent evidence showing that in the absence of any type of brain injury, errors in speech are subject to learning.

Errors in Speech

There is growing awareness among language researchers that the adult language system incrementally and inexorably tunes itself in the course of perceiving and producing language. This "incremental language learning" is considered integral to the explanation of diverse frequency effects, repetition priming, structural priming, semantic blocking, and perseveration (Chang, Dell, & Bock, 2006; Howard, Nickels, Coltheart, & Cole-Virtue, 2006; Hsiao, Schwartz, Schnur & Dell, 2009; Oppenheim, Dell, & Schwartz, 2010; Schnur, Schwartz, Brecher, & Hodgson, 2006). Computational accounts frequently invoke *Hebbian learning*, a popular notion in neuroscience that captures the idea that neurons that "fire together, wire together," (Hebb, 1949). In other words, Hebbian learning strengthens a pattern of activation leading to a response given a specific input, such that the same response is made more likely subsequently given the same input.[3] Hebbian learning is agnostic to outcome, so that patterns of activation that lead to errors are strengthened in the same way as those that lead to accurate responses (see Fillingham, Hodgson, Sage & Lambon Ralph, 2003 for discussion). In line with this, recent research with neurologically-intact speakers provides evidence that word retrieval failures and sound errors in speech are indeed learned.

In an initial investigation, Warriner and Humphreys (2008) focused on *tip-of-the-tongue* (TOT) states, where speakers have a word in mind but are momentarily unable to retrieve the phonology (i.e., the sounds) of the word. TOT phenomena are consistent with the generally accepted view that word retrieval is a multi-stage process (for review, see Vigliocco & Hartsuiker, 2002). The first stage involves mapping a concept to a non-phonological word representation, or lemma, and the second stage involves retrieval of the corresponding phonological form (for computational implementations of this approach, see Dell, 1986; Levelt, Roelofs, & Meyer, 1991). TOT states are generally interpreted as indicative of successful lemma selection, but stymied phonological access.

To elicit TOTs, Warriner and Humphreys (2008) gave healthy young adults definitions to low frequency words. If participants could not produce the target, they indicated when they were in a TOT state versus when they did not know the target word. For each TOT state, the experimenter gave the participant 10 seconds or 30 seconds--randomly assigned--to continue to attempt to retrieve the word's phonology. The authors hypothesized that the longer a participant was allowed to remain in a TOT state, the more a dysfunctional pattern of

[3]Note that although the cognitive representations that arise to mediate stimulus-response pairings may be predominantly formed through Hebbian learning, there can be a role for feedback that ameliorates such learning (see Vallabha & McClelland, 2007 for computational approach; McCandliss, Fiez, Protopapas, Conway & McClelland, 2002 for discussion).

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retrieval would be reinforced, which would lead to greater difficulty with that word when the test was repeated. In confirmation of this, they found that when participants were allowed to remain in a TOT for 30 seconds versus 10 seconds in the first session, they were more likely to experience a TOT for that item in a second session held 48-hours later. Warriner and Humphreys interpreted their findings as evidence for error learning, which in terms of TOTs, may involve the strengthening of incorrect links to phonology.[4]

In subsequent work, Humphreys, Menzies and Lake (2010) found evidence suggesting that word onset errors are learned. Humphreys et al. used the SLIP task (*spoonerisms of laboratory induced predisposition;* Baars, Motley & MacKay, 1975) where word pairs are presented, and participants are instructed to read them silently except when cued to produce a pair aloud. In some instances, the phrase to be produced (e.g., *peg bet*) is preceded by phrases (e.g., *bull pines*, *best poll*, *bell pun*, etc) that prime a particular sequence of onsets (e.g., b___ p___). This sometimes leads to onset errors on the enunciated pair (e.g., partial onset error such as *beg bet* or full onset exchanges such as *beg pet*). Humphreys et al. (2010) found that onset errors were more likely at a subsequent presentation if an item had resulted in an onset error in an initial presentation than if no onset error had initially occurred. For full onset exchanges specifically, they found a 10-fold increase in error likelihood from having previously made an error (versus not having made an error at initial presentation).

The work by Humphreys and colleagues suggests that errors in speech are subject to learning. Thus, it lends credence to the idea that error learning might be a complicating factor in aphasia rehabilitation irrespective of the status of explicit memory in these individuals. Certainly, TOT-like phenomena are well documented in aphasic naming, particularly in individuals who qualify as having pure anomia (a.k.a. classical anomia; see Badecker, Miozzo, & Zanuttinni, 1995; Lambon Ralph, Sage, & Roberts, 2000). The sound errors studied by Humphreys et al. (2010) involve movement between words and therefore have less direct parallel with errors in naming. Nevertheless, the demonstration that erroneous phonological productions are subject to learning is potentially relevant to naming errors that arise during the second (phonological) step of lexical access and/or in post-lexical sequencing operations (e.g., Dell, Schwartz, Martin, Saffran & Gagnon, 1997; Goldrick & Rapp, 2007). In summary, the studies by Humphreys and colleagues lend plausibility to the idea that anomic states and retrieval errors might be learned in aphasia.

Accepting this premise, it is still an open question whether naming treatments that avoid or minimize errors are at an advantage relative to errorful approaches. The answer to this question hinges on the strength of error learning in aphasia and the importance of retrieval practice for the recovery of word retrieval. To date, we have little direct evidence on either of these issues. However, a number of studies have compared errorless and errorful approaches to the treatment of aphasic word retrieval, and it is possible to draw tentative conclusions from these.

Before turning to this literature, we should explain that comparisons of EL and EF approaches in aphasia have primarily targeted picture naming, and our review will reflect this bias. Picture naming is widely used for eliciting, classifying, and treating word retrieval deficits in aphasia (e.g., Best, Herbert, Hickin, Osborne, & Howard, 2002; Dell et al., 1997; Howard, Patterson, Franklin, Orchard-Lisle, & Morton, 1985a, 1985b; Lorenz & Nickels, 2007) and naming treatments are well-suited to manipulations of error likelihood. In the

[4]This work is not without interpretive difficulty. Their key result involved performance at session 2 for items in two groups: (1) items that were assigned to the short condition *and* that were not resolved within 10 seconds at session 1; (2) items that were assigned to the long condition *and* that were not resolved within 30 seconds at session 1. Such an analysis may have introduced a selection bias in that items in the latter group may tend to be more difficult (i.e., they are by definition hard enough to require at least 30 seconds to resolve).

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standard EL treatment for picture naming ("repetition training"), the target is presented in conjunction with its spoken and/or written name, which the participant then reproduces. In the standard EF approach, the picture is named following a weaker cue (e.g., first phoneme or letter) or with no cue provided ("confrontation naming training"), after which the name may be provided as feedback depending on the study.

A naming treatment involves retrieval practice to the extent that it calls for the name to be retrieved from long-term (i.e., lexical) memory. Confrontation naming training clearly meets this criterion. Repetition training clearly does not. Repetition is a classic short-term memory task, which, depending on one's theory of STM involves temporary storage of the word in one or more specialized buffers (Baddeley, 1986; Martin, Shelton, & Yaffee, 1994) or temporary activation of its LTM representations (e.g., Martin & Saffran, 1997; Postle, 2006). On either account, naming treatments that precede a retrieval attempt with repetition or reading of the target do not fully engage retrieval practice because of the potential support from STM.

Errorless Learning in Aphasic Word Retrieval

Fillingham et al. (2003) first investigated the relative efficacy of EL and EF therapies of naming in a review of the naming treatment literature in aphasia. They classified treatment studies as EL (the study employed methods that reduced or eliminated errors), or EF (all other studies). Each study was assessed for whether it led to reliable treatment effects on treated words assessed post-therapy (one to several days post) and again after follow-up (usually weeks to months post). Generalization to untreated words was also noted when present. Across all studies, including those employing expressive training, receptive training, mixed or non-language, the percentage of studies that generated post-therapy benefits was comparable for EL (72%) and EF (79%). (Note that inferential statistics were not provided.) The percentage that generated follow-up benefits was numerically higher for EF (59%) than EL (47%). Generalization effects also were more often obtained with EF (38%) than EL (15%). When the analyses were restricted to studies that only involved expressive training, EL treatments tended to outperform EF, but EF tended to outperform EL treatments in terms of reliable follow-up effects and presence of generalization. Thus, overall, there were nonsignificant trends hinting at a greater benefit from EF methods, but EL methods did not suffer in the comparison.

The work of Fillingham et al. (2003) was an important first attempt to divine the relative efficacy of EL and EF interventions of naming impairments in aphasia. However, the studies they reviewed and classified as EL or EF could have differed on a number of relevant dimensions, including intensity of training, severity of patients, specific impairment being trained, and regularity of feedback. A series of studies followed that directly compared EL and EF naming treatments in chronic aphasia with controlled single-subject experiments (Conroy et al., 2009b; Fillingham et al., 2005a, 2005b, 2006; McKissock & Ward, 2007). The general approach in this body of work was to compare performance gains on items given standard EL or EF treatment (defined above). Treatment effects within and across patients were assessed by measuring gains over baseline performance on tests held one or more days after therapy (i.e., post-therapy effects). Long-term treatment effects were measured by comparing performance on a follow-up test held one or more weeks later to performance at baseline.

Across studies, the general finding was that both EL and EF methods lead to post-therapy gains for most patients, with neither method emerging as consistently superior. However, closer analysis of the studies reveals indications that retrieval practice may influence EF treatment efficacy. One indication is that EF treatments can be as efficacious as EL methods even when EF treatment is at a disadvantage from lack of feedback (Fillingham et al.,

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2005a; 2005b; cf. McKissock & Ward, 2007). In Fillingham et al., (2005a) on each trial of EL treatment, the spoken/written name accompanied the picture and the participant was given the opportunity to repeat it three times in immediate succession. On each trial of EF treatment, the name-onset cue accompanied the picture and the participant was asked to name it three times in immediate succession. Each item was trained in three separate trials in each of ten sessions of therapy. Overall, this means that participants were given the opportunity to repeat items in EL treatment 90 times. In contrast, the correct response was never provided in the EF condition. In spite of this, five of seven participants showed immediate treatment effects in the EF condition, compared with six in the EL condition. At follow-up, six patients demonstrated long-term treatment effects (measured against initial baseline) in the EF condition compared to five in the EL condition (see Fillingham et al., 2005b for similar findings).

Later studies supplemented EF treatment with feedback to equate informational support between EF and EL techniques. McKissock and Ward (2007) compared standard EL treatment to EF treatment involving confrontation naming. However, in contrast to earlier studies (e.g., Fillingham et al., 2005a; 2005b), onset cues were not provided during EF treatment and in one EF condition, all naming attempts were followed by feedback. In that study, the EF plus feedback condition performed equivalently to the EL condition at a group level, both in terms of immediate and long-term measures of treatment effects. In the EF condition of Fillingham et al., (2006), on each training trial failure to name was followed by cues of increasing specificity until naming was achieved (e.g., first phoneme/letter provided→first syllable provided→full word provided for repetition). Here, EL and EF showed immediate therapy effects of similar magnitude for most patients. However, at follow-up, five patients showed long-term treatment effects for items trained by both approaches whereas an additional four showed a benefit for items trained by the EF approach only. In contrast to the EF procedure of McKissock and Ward (confrontation naming), the cueing hierarchy procedure employed by Fillingham et al. may have increased the likelihood of *successful* retrieval practice during training, promoting greater treatment efficacy relative to EL treatment.

The foregoing studies reveal some important patterns. First, the reduction in errors associated with EL training does not necessarily translate into better learning. EF methods can lead to comparable performance as EL methods when assessed within days of therapy (Fillingham et al., 2005a; 2005b; 2006). After longer intervals, EF methods tend to outperform EL methods (Fillingham et al., 2003; 2006). There is also an indication that EF treatment gains may be enhanced by cueing the response (Fillingham et al., 2006) and/or providing feedback following the errorful retrieval attempt (McKissock & Ward, 2007). Taken together, the reviewed studies hint at greater efficacy potential of EF treatments over EL methods, particularly when long-term treatment effects are considered.

A topic of potentially great relevance to the efficacy of EF and EL approaches is individual patient characteristics. Fillingham and colleagues have taken important early steps towards identifying the contribution of profile of impairment to treatment outcomes (Fillingham et al., 2005a; 2005b; 2006; Lambon Ralph, Snell, Fillingham, Conroy, & Sage, 2010; see also Fillingham et al., 2003 for discussion). Across these studies, aphasic individuals who benefitted most from *either* EL or EF treatment were those who performed better on measures of memory, executive function, and monitoring their own errors. Moreover, in Fillingham et al., (2006) the differential benefit of EF relative to EL treatment similarly correlated with non-language functions, specifically attention, recall memory, and working memory.

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As noted by Lambon Ralph et al., (2010), insufficient power in the earlier Fillingham studies may have concealed additional predictors of response to therapy. In a principle components analysis with a large sample drawing from multiple studies including data from Fillingham et al., 2006, Lambon Ralph et al., (2010) found that degree of improvement from EF treatment involving the accumulating cues procedure (see Fillingham et al., 2006) was accounted for by two main factors: a cognitive skills factor (e.g., executive function, attention, memory) and a language factor (e.g., pre-intervention naming performance). It would be very useful to see a similar analysis applied to the identification of patient characteristics predictive of differential response to EL and EF treatments. However, it is important that the studies contributing to such an analysis employ EF methods that maximize the impact of retrieval practice. After a brief discussion of evidence indicative of retrieval practice effects in the existing aphasia literature, we outline experimental approaches designed to compare EL treatments in aphasia against EF treatments that capitalize on the powerful learning effects of spaced retrieval practice.

Retrieval Practice and Spacing Effects in Aphasic Word Retrieval

In the previous section, we identified trends indicating superior retention of treatment gains with EF compared to EL methods. We interpret these trends as indicative of the operation of retrieval practice effects on aphasic word-retrieval under EF conditions. On what do we base this? Part of the rationale draws on accumulating evidence that incremental learning-by-using happens throughout the lifespan (e.g., Chang et al., 2006; Vallabha, & McClelland, 2007; Warker & Dell, 2006), and that both Hebbian learning (Fillingham et al., 2003; Warriner & Humphreys, 2008) and error-based learning (Oppenheim et al., 2010) operate during word retrieval to influence the probability of future success. Thus, insofar as general-purpose memory and learning mechanisms operate in both aphasic and normal word retrieval, it is at least plausible that aphasic word retrieval is subject to retrieval practice effects.

Furthermore, there are research findings consistent with the expectation that retrieval practice impacts aphasic naming. A number of studies show that items that are subject to repeated naming attempts are named better than they would be without such exposure, even in the absence of feedback (e.g., Fillingham et al., 2005a; 2005b). In Howard et al.'s (1985b) study exploring the facilitation of naming from word-to-picture matching, a subset of control items were named with the same frequency as treated items, but were not otherwise treated. For present purposes, the interesting finding is that performance on these control items improved with repeated naming attempts, and, in one experiment, were named with equivalent success as treated items (Experiment 4). Though such a finding would usually be attributed to generalization from an intervention to control words, an alternative is that it reflects learning through repeated naming attempts (i.e., from retrieval practice). In support of this, Nickels (2002) found that naming treatments involving no more that repeated naming attempts yielded improvement on final naming measures, as did treatments involving reading words and copying them. The naming treatment was not conducted concurrently with any other type of treatment and hence, its effects were not attributable to generalization. Nickels' results led her to conclude that naming “practice makes (closer to) perfect, even without correction” (p. 1058).

Evidence consistent with a beneficial impact of retrieval practice on aphasic word retrieval also can be found in treatment research using cueing hierarchies. The expectation from a desirable difficulties standpoint is that an accumulating cues schedule will be associated with greater treatment gains than vanishing cues (see Finley et al., 2011 for discussion). Accumulating cueing begins each trial with the most difficult naming condition (confrontation naming), and thus is more likely to engage effortful retrieval than vanishing cues, which starts with the target response (at least on early trials). Consistent with this,

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Abel, Schultz, Radermacher, Willmes and Huber (2005) found that more patients benefitted from treatment involving accumulating cues and/or a mixed treatment (both types of cueing hierarchy), than treatment that involved only vanishing cues. On the other hand, Conroy et al., (2009a) did not find an advantage for accumulating cues over vanishing cues in naming treatment for nouns and verbs. Clearly, more research is needed to determine under what circumstances accumulating schedules, which are more likely to result in error but also to create conditions that exploit desirable difficulty, outperform vanishing cues schedules in aphasia.

Researchers have yet to systematically investigate the effects of spacing on aphasic naming. In preliminary work, Fridriksson, Holland, Beeson, and Morrow (2005) found superior long-term treatment gains from naming attempts programmed according to an adjusted expanding schedule (defined above) versus vanishing cues treatment. Following this, Morrow and Fridriksson (2006) found similar benefits from an adjusted expanding schedule compared to a schedule where the interval until next test was randomly selected for an item. Important to note, these studies do not permit conclusions about the effects of spacing on aphasic naming performance per se, as neither study included a massed test schedule. A massed schedule of learning is important to include as it controls for the number of training exposures to an item, and (with comparison to a distributed schedule) permits identification of the basic effect of spacing on performance.

Errorless Learning in Aphasic Word Retrieval: Synthesis and Future Directions

The errorless learning approach in aphasic word retrieval is compelling to the degree that error learning in aphasia exists, and robustly can impact performance. Future research aimed at addressing this issue could employ techniques that manipulate the time in a failed retrieval state (Warriner & Humphreys, 2008), or the occurrence of error (Humphreys et al., 2010). The magnitude of error learning's impact on performance could be assessed, particularly as a function of repeated errors. Whereas Humphreys et al., (2010) found a ten-fold increase in error likelihood from one earlier incidence of error, future research could explore the ramifications on ultimate performance of erring on the same item more than once, which is common in aphasia. It would also be important to establish the longevity of error learning in aphasia, which Humphreys and colleagues found to depend on the type of error. If error learning were demonstrable in adaptations of such paradigms, the next important step would be to compare EL methods to training involving retrieval practice when its effects are maximized. In other words, whether errors should be avoided during treatments of aphasia could be decided on pragmatic grounds, in a strong test of errorless methods.

The first step in developing a strong test of the errorless learning approach is to establish an unequivocal role for retrieval practice on aphasic naming through careful experimentation. One could employ a facilitation design to maximize statistical power and experimental control, wherein one evaluates the effect of a single treatment event per item on subsequent naming performance (Howard et al., 1985b). An effect of retrieval practice would be established if training where retrieval is possible (e.g., naming tests with phonemic/orthographic onset or hierarchical cueing followed by feedback in case of error) led to better subsequent naming accuracy than training involving standard errorless learning (i.e., repetition).

The next step would be to compare the impact of retrieval practice when its effects are maximized to standard errorless training in extended treatment paradigms. To illustrate, the Pashler et al., (2003) paradigm (described earlier) could first be used to guide the construction of optimized distributed schedules of learning.[5] This would involve manipulating the lag between initial presentation of an item for repetition and a naming test (i.e., training lag) to diagnose the lag that taps desirable difficulty. Once established for a group given a level of severity or for the individual, the optimal training lag could be used as the fixed lag in a fixed-distributed schedule or as the initial lag in an expanding distributed schedule, with errorless events (i.e., repetition) programmed according to the same schedule. To exemplify: Let us suppose that the first exposure to an item is a repetition trial. Subsequent trials involving the same item would involve naming attempts (i.e., repeated tests) with feedback, or repetition (i.e., standard errorless training), where an item is presented according to the "optimized" distributed schedules or other schedules of interest. Such an approach would illuminate two issues, first to what degree training involving retrieval practice outperforms standard errorless learning (measured as the difference in final naming performance after repeated naming trials or repetition trials), and second, how optimized test schedules fare with respects to other schedules.

To recap, newly developed methods in cognitive psychology provide experimental means to assess the impact of error learning in aphasic word retrieval. Resolution of this issue will provide much-needed perspective on whether the avoidance of errors in naming treatment in aphasia should be a priority. However, even if error learning in aphasia is demonstrated to exist in such paradigms, the recommendation for the clinic should be based on controlled comparisons between EL treatments and EF treatments that maximize the effects of retrieval practice. We have illustrated a program of research aimed to do this. Given that retrieval practice effects and spacing effects are among the most powerful and robust phenomena in cognitive psychology, proving almost universal in their relevance to performance in countless domains and across a broad range of populations, we are eager to see the outcomes of such empirical contests.

Conclusion

This paper attempts to bridge the various literatures pertaining to errorless learning in aphasia and amnesia, error learning in the speech of neurologically-intact controls, and spacing and testing effects in clinical and nonclinical populations. In doing so, it has generated many (many) more questions than answers. Fortunately, many of these are empirical questions, open to investigation through the types of paradigms that are readily available to clinical researchers (e.g., single-case facilitation and treatment studies). We have chosen to highlight these questions and these paradigms in our review and recommendations for future research. Our hope is that by building bridges between psychology research on testing/spacing effects, on the one hand, and neuropsychological research on errorless learning, on the other, we can promote the development of maximally efficacious interventions in cognitive rehabilitation.

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[5]The Pashler et al. (2003) training paradigm manipulated the lag between two test events, which followed an initial study event. In terms of word retrieval, we draw the parallel that trying to retrieve a name from lexical memory (i.e., naming) is a form of "test", whereas producing the name immediately after hearing or reading it in repetition training is akin to engaging in "study".

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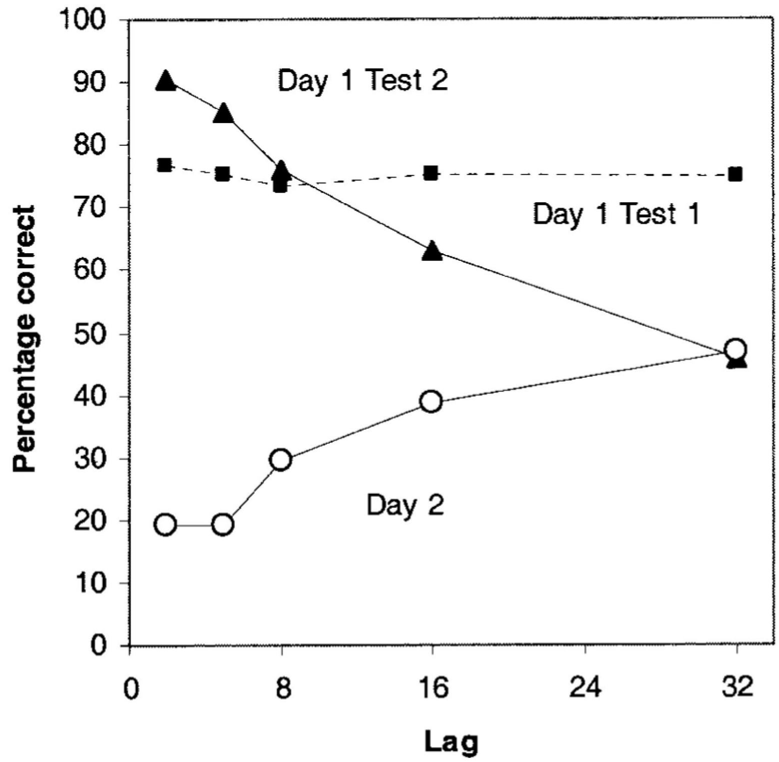

Figure 1.
The abscissa corresponds to lag between Test 1 (squares) and Test 2 (triangles) at Day 1; the ordinate corresponds to test performance. Day 1 Test 2 shows increased errors during training as a function of lag, whereas the final test at Day 2 (circles) shows improved retention of learning with increasing lag between Test 1 and Test 2 during Day 1. See text for description. From "Is Temporal Spacing of Tests Helpful Even When It Inflates Error Rates," by H. Pashler, G. Zarow, & B. Triplett, (2003). Journal of Experimental Psychology: Learning, Memory & Cognition, *29*, p. 1053. Copyright 2003 by American Psychological Association, Inc.

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