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A Review of the Application of Distributed Practice Principles to Naming Treatment in Aphasia

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It is uncontroversial in psychological research that different schedules of practice, which govern the distribution of practice over time, can promote radically different outcomes in terms of gains in performance and durability of learning. In contrast, in speech–language treatment research, there is a critical need for well-controlled studies examining the impact of distribution of treatment on efficacy. In this article, we enumerate key findings from psychological research on learning and memory regarding how different schedules of practice differentially confer durable learning. We review existing studies of aphasia treatment with a focus on naming impairment that have examined how the distribution of practice affects treatment efficacy. We close by discussing potential productive lines of research to elaborate the clinical applicability of distributed practice principles to language treatment. **Key words:** *aphasia*, *cognitive rehabilitation*, *distributed practice*, *lag effect*, *lexical access*, *naming treatment*, *retrieval practice*, *spacing effect*, *treatment intensity*

IN APHASIA treatment research, there remain many unanswered questions regarding the optimal distribution of treatment for maximizing efficacy and the retention of gains. This article explores the potential applicability of principles of distributed practice for enhancing the potency of treatment of naming impairment in aphasia, with a focus on how the principles impact naming accuracy on treated items. The principles of learning indicate that training trials for items are more potent when spaced over time than massed in close succession (Principle 1), and with increases in spacing within a session (Principle 2). Furthermore, training trials for items are more potent when distributed across sessions rather than within a single session (Principle 3). Finally, greater time between sessions can enhance learning and retention (Principle 4). We first outline the empirical basis for these four principles in the cognitive and educational psychology literatures. We then review findings of naming treatment studies that have examined how the spacing of trials for trained items within or across sessions impacts later performance on trained items. Findings from studies on speech–language treatment intensity that may

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relate to the learning principles are also reviewed. The article concludes with directions for future research to advance the translation of basic learning principles for informing and improving language rehabilitation.

PSYCHOLOGICAL PRINCIPLES OF LEARNING

Because the focus of this article is application to language treatment, we review evidence relevant to verbal learning. In psychological studies with neurotypical participants, common examples of to-be-learned (i.e., *target*) information in the verbal domain include learning the association between two words or the translation for foreign words. A large literature in psychology has examined how the *scheduling* of repeated training trials per item affects learning and retention. This literature has developed in lockstep, with research examining how the *type* of practice affects durable learning. Specifically, countless studies have shown that *retrieval practice*, or practice retrieving target information (e.g., the English translation of a Swahili word) from long-term memory, confers robust learning relative to restudying that information (for a review, see Rowland, 2014). The primary purpose of the current article is to examine the state of the field with regard to the applicability of distributed practice principles to aphasia treatment, but new research on retrieval practice effects in aphasia is also briefly discussed to give greater context to our current understanding of how language treatment responds to these related learning principles.

SCOPE OF THE EVIDENCE TO BE REVIEWED

The primary purpose of this review is to discuss the use of distributed practice principles to optimize the scheduling of naming treatment for the promotion of consistent retrieval of trained words for production in people with aphasia. Naming impairment, or difficulty retrieving and producing the words for objects, actions, people, and so forth, is ubiquitous across the different subtypes of aphasia and commonly a central impediment to successful communication (Goodglass & Wingfield, 1997). Although producing a name requires multiple stages of processing (for overview, see Wilshire, 2008), a common cause of naming difficulty in aphasia is an impaired ability to map from semantics to existing, but inconsistently retrievable, lexical representations (i.e., words; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Rapp & Goldrick, 2000; Walker & Hickok, 2016). Similar to methods used in psychological research on learning and memory, naming treatment of aphasia commonly involves practice retrieving specific words such as names for pictured objects or actions in several separate trials over the course of one or more sessions, and a subsequent test can assess the patient's performance for the trained items. Therefore, in aphasia research, the treatment of naming impairment is an ideal domain for examining how distributed practice principles may impact efficacy.

In addition to these item-specific effects, improved naming of untrained items (i.e., generalization) is often an important goal of naming treatment. Not unlike the distributed practice literature, the applicability of the learning principles outlined in this article for generalized improvement in naming is less clear than for item-specific improvements in accuracy. It also remains uncertain whether these principles apply in treatments focusing on more complex or abstract linguistic processes (e.g., phrase or sentence production; syntactic parsing). Although we return to these issues in the final sections of the article, the primary purpose of this review is to discuss how distributed practice principles might optimize naming treatment that focuses on benefits to treated vocabulary for people with aphasia.

DISTRIBUTED PRACTICE EFFECTS: SPACING AND LAG

A *distributed practice effect* refers to any result in which the distribution of an item's practice trials across more (vs. less) time or a greater (vs. fewer) number of intervening trials for other items confers superior performance at a later test. The voluminous literature on distributed practice generally shows that performance during training is a poor indicator of learning. Greater distribution of an item's trials is generally associated with more forgetting between trials during training but better long-term retention of information after training (for discussion, see Schmidt & Bjork, 1992). Research on the effects of distributed practice has focused on four basic comparisons summarized in Table 1 and discussed briefly in the following text in order of manipulations involving shorter to longer timescales. For brevity and ease of exposition, we identify each comparison with a learning principle (see Table 1, Column 1) and refer to such principles in relation to the reviewed studies (see Tables 2 and 3, Column 2).

The first comparison involves spaced versus massed practice within a training session (Principle 1). In *massed practice*, an item's trials are presented in close enough succession that the item remains active in working or short-term memory across its trials. In contrast, *spaced practice* refers to conditions in which an item's training trials are separated by enough time and/or trials for other items so that processing of the item on each of its trials requires involvement of long-term memory. When performance during training is probed (e.g., via retrieval practice), a typical finding is that performance is superior during massed

Table 1. Distributed practice comparisons ordered from shorter to longer time spans with typical performance patterns and associated learning principles

Learning Principle	Condition	Description	Performance During Training	Performance After a Delay
1	Massed practice	An item's trials separated by zero or one other trial	Massed > spaced	Spaced > massed
	Spaced practice	An item's trials separated by more than one other trial		
2	Shorter trial lag within a session	An item's trials separated by fewer other trials	Shorter trial lag > longer trial lag	Longer trial lag > shorter trial lag
	Longer trial lag within a session	An item's trials separated by more other trials		
3	Within-session training	An item's trials trained in one session	# of correct retrievals typically controlled across conditions	Across-session training > within-session training
	Across-session training	An item's trials trained in two or more sessions		
4	Shorter intersession lag	Each session separated by fewer days	Shorter intersession lag > longer intersession lag	Longer intersession lag > shorter intersession lag
	Longer intersession lag	Each session separated by more days		

Table 2. Characteristics of naming treatment studies and learning principles examined

Study	Learning Principle	*N*	Design	Type of Treatment	Massed/Shorter Lag Condition	Spaced/Longer Lag Condition	Timing
Raymer, Kohen, & Saffell (2006)	4	5 C	Two phases (WS)	Word-picture matching and name repetition	Three to four sessions per week for 12 sessions total	One or two sessions per week for 12 sessions total	Throughout treatment; 1-month retention probe
Ramsberger & Marie (2007)	4	4 C	Two phases (WS)	Cued naming	Five sessions per week	Two sessions per week	Every fifth treatment session
Sage, Snell, & Lambon Ralph (2011)	4	8 C	Two phases (WS)	Confrontation naming, followed by cueing	Five sessions per week for 2 weeks	Two sessions per week for 5 weeks	Immediately posttreatment; 1-month retention probe
Middleton, Schwartz, Rawson, Traut, & Verkuilen (2016)	1, 2	4 C	One phase (WS)	Retrieval practice or name repetition and correct answer feedback	Massed practice in one session	Spaced practice in one session	1-day and 1-week retention probes
Middleton, Rawson, & Verkuilen (2019)	1	4 C	One phase (WS)	Retrieval practice or name repetition and correct answer feedback	Massed practice in four sessions	Spaced practice in four sessions	1-week and 1-month retention probes
Schuchard, Middleton, & Rawson (2019)	3	9 C	Two phases (WS)	Retrieval practice and correct answer feedback	Retrievals presented within one session	Retrievals distributed across two sessions	1-day and 1-week retention probes
	4				Intersession lag = 1 day for three sessions	Intersession lag = 7 days for three sessions	1-month retention probe

Note. N refers to number of participants; in that column, *C* = aphasia in the chronic phase (>3 months postonset). *Design* refers to type of experimental design, where *WS* = within-subject. *Timing* denotes when naming performance was probed during and after treatment.

Table 3. Characteristics of other language treatment studies and learning principles examined

Study	Learning Principle	*N*	Design	Type of Treatment	Shorter Lag Condition/Group	Longer Lag Condition/Group	Timing
Harnish, Neils-Strunjas, Lamy, & Eliassen (2008)	4	1 C	Two phases (WS)	Naming, sentence production, writing	1.5-hr sessions; five sessions per week for 2 weeks	1-hr sessions; two sessions per week for 7.5 weeks	Unspecified interval after each treatment phase
Martins et al. (2013)	4	30 (18) A	Randomized, rater-blinded, parallel trial (BS)	Multimodal stimulation approach (e.g., Schuell, Carrol, & Street, 1955).	Five sessions per week for 10 weeks	One to two sessions per week for 50 weeks	10, 50, and 62 weeks after initiation of treatment
Mozeiko, Coelho, & Myers (2016)	4	8 C	Modified multiple baseline design across subjects (BS)	Constraint-induced language therapy	3-hr sessions; five sessions per week for 2 weeks	1-hr sessions; three sessions per week for 10 weeks	After every 6 hr of treatment; 1-week and 1-month retention probes
Dignam et al. (2015); Dignam, Copland, et al. (2016)	4	34 (32) C	Nonrandomized parallel-group trial (BS)	Aphasia language impairment and functioning therapy (Rodriguez et al., 2013)	16 hr per week for 3 weeks	6 hr per week for 8 weeks	Immediately posttreatment; 1-month retention probe

Note. *N* refers to number of participants (total participants who completed the study to the primary endpoint); in that column, *A* = acute or subacute (<3 months postonset) and *C* = chronic (>3 months postonset). *Design* refers to type of experimental design, where *WS* = within-subject and *BS* = between-subjects. *Timing* denotes when performance was probed during and after treatment.

versus spaced training. In contrast, on a subsequent test of performance administered after training (i.e., *retention test*), spaced practice confers an advantage over massed practice. This *spacing effect* is one of the most replicated and reliable effects in human learning research; one meta-analysis found that 259 of 271 (96%) of comparisons revealed a significant advantage for spaced over massed practice at retention test (Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006; see also Delaney, Verkoeijen, & Spirgel, 2010; Toppino & Gerbier, 2014).

The second comparison involves longer versus shorter spacing within a training session (Principle 2). Within the context of spaced practice, the degree of spacing between an item's training trials is referred to as *lag.* Increases in lag typically enhance retention test performance (for review, see Cepeda et al., 2006). For example, Pyc and Rawson (2012) presented learners with foreign language translations for an initial study trial and then three practice trials. Trials for a given item were separated by either 9 or 69 practice trials for other items. On a retention test administered 2 days later, performance was considerably greater for items that had been practiced with longer versus shorter lags between trials.

The third comparison involves practice that is distributed across two or more training sessions versus completed within a single training session (Principle 3). Real-world learning situations commonly involve training on a set of materials or skills in multiple sessions with an aim to promote maintenance of learned information over intervals of weeks, months, or even years. Yet, only a small minority of psychological studies of distributed practice in the verbal domain have included multiple training sessions. Some studies have held the total number of training trials per item constant and manipulated whether the training trials for a given item are all completed in one session or distributed across sessions (e.g., Kornell, 2009). Other studies have presented items for retrieval practice until each is successfully retrieved a predetermined number of times, and the successful retrievals for a given item are accomplished either in one session or spread across multiple sessions (e.g., Rawson & Dunlosky, 2011; Vaughn, Dunlosky, & Rawson, 2016). Across studies involving these methodologies, the consistent outcome is that retention test performance is greater following practice that was distributed across multiple sessions versus completed in a single session. To illustrate, consider the recall accuracy for trained Swahili–English word pairs reported by Vaughn et al. (2016). Participants' average accuracy was only 28% 1 week after items had been practiced to a criterion of *four correct trials* per item within *one session* compared with 74% accuracy 1 week after items had been practiced to a criterion of *one correct trial* per item in each of *four sessions* spaced a week apart.

The fourth comparison involves training sessions that are separated by longer versus shorter intervals (Principle 4). When items are presented for practice in two or more sessions, relatively few studies have examined the effects of increasing the lag between practice sessions (hereafter, *intersession lag*). For example, in the study by Bahrick, Bahrick, Bahrick, and Bahrick (1993), the task involved practice translating unfamiliar foreign vocabulary. Items were practiced in multiple sessions that were separated by intervals of 14, 28, or 56 days. On retention tests administered 1, 2, 3, 4, or 5 years after the last practice session, performance was superior for items in the 56-day lag condition versus the 28-day lag condition, which, in turn, was superior to the 14-day lag condition. More recently, Rawson, Vaughn, Walsh, and Dunlosky (2018) found modest gains on a retention test administered 1 month after practice when prior training sessions were separated by 7 days versus 2 days (for similar outcomes, see Cepeda, Vul, Rohrer, Wixted, & Pashler, 2008). Taken together, these findings suggest that increasing intersession lag may enhance the durability of learning, although strong conclusions about the magnitude of these benefits and about optimal intersession lags await further research.

DISTRIBUTED PRACTICE PRINCIPLES

To summarize the findings discussed earlier, psychological learning research with neurotypical adults supports the following principles of distributed practice (Table 1):

1. Training trials per item within a session are more potent when they are spaced versus massed (Principle 1) and when spaced trials are separated by a longer versus shorter lag (Principle 2).
2. Training trials per item are more potent when distributed across sessions rather than administered within a single session (Principle 3).
3. Increasing intersession lag can enhance durable learning (Principle 4).

APPLICABILITY OF DISTRIBUTED PRACTICE PRINCIPLES TO APHASIA TREATMENT

There are several potential barriers to the translation of findings from experimental psychology to a language treatment setting. Even among neurotypical populations, there is a pressing need for more research on the relevance of distributed practice principles in the context and timescale of real-world learning (for review, see Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013). Another barrier may be that the psychology literature has focused on factors that optimize the acquisition of new knowledge, whereas the functional deficit underlying aphasia generally reflects inconsistent or disordered access to existing representations that underpin language use (for review, see Mirman & Brit, 2014). Furthermore, there may be important differences in learning systems between neurologically intact adults and individuals with neurological damage. Stroke-induced neurophysiological changes are likely to affect mechanisms of learning, particularly in the initial months following brain injury (Kleim & Jones, 2008). Brain damage may also cause long-lasting impairments to domain-specific or domain-general learning processes that are relevant to language processing and recovery (e.g., Schuchard & Thompson, 2014; Tuomiranta et al., 2014; Vallila-Rohter & Kiran, 2013). Considering these complicating factors, the optimal learning strategies for at least some individuals with aphasia likely differ from those established by psychological learning research.

Nevertheless, a growing body of research supports the hypothesis that people with aphasia engage learning processes in their recovery of language abilities (for review, see Vallila-Rohter, 2017) and suggests that basic learning principles also apply to naming treatment efficacy in aphasia. Evidence is amassing for the clinical applicability of retrieval practice (see the "Psychological Principles of Learning" section) to the treatment of naming impairment in aphasia. Numerous recent studies have contrasted naming treatment that provides retrieval practice (i.e., practice retrieving names for depicted entities from long-term memory) to name repetition training, a parallel to the restudy condition in psychological studies of retrieval practice effects. Name repetition training is a common form of naming treatment that involves practice orally repeating experimenter-provided names for depicted objects, but notably, production does not require retrieval of the name from long-term memory. Consistent with retrieval practice research on neurotypical individuals, these studies have all observed superior naming accuracy after retrieval practice versus name repetition training on retention tests administered at intervals ranging from days to months (Friedman, Sullivan, Snider, Luta, & Jones, 2017; Middleton et al., 2016, 2019; Middleton, Schwartz, Rawson, & Garvey, 2015). Additional studies have shown that retrieval practice is particularly efficacious for strengthening connections between meaning and words in the course of lexical access (Schuchard & Middleton, 2018a, 2018b). Likewise, as we review later, a growing literature is pointing to the applicability of distributed practice learning principles for enhancing naming treatment benefits.

In the following section, we review the results of aphasia rehabilitation studies that contribute to an understanding of the relationship between distributed practice principles and treatment efficacy. To date, the majority of studies that have examined effects of how treatment is distributed in aphasia can be divided into two general categories. One category consists of naming treatment studies that employ a within-subjects design in which sets of items (e.g., depicted objects for naming practice) are assigned to different schedules. Manipulations include the spacing of trials for specific items within or across sessions or the lag between sessions. These studies primarily evaluate item-specific effects (i.e., naming accuracy for trained items). The second category consists of studies of treatment protocols that address multiple aspects of language and communication, employing a between-subjects design in which participants are assigned to one of two different schedules. These studies typically manipulate the spacing of treatment hours or sessions dedicated to multimodal speech–language treatment and evaluate outcomes using relatively comprehensive tests of language and/or functional communication. Although the naming treatment studies are more relevant for the focus of the current article, we also discuss evidence from other types of language treatment in aphasia to highlight similarities and differences between the two categories of treatment schedule research.

Distributed practice effects in naming treatment of aphasia

We next review evidence from studies examining schedules of practice in naming treatment identified from literature searches conducted in March 2018. Searches on Web of Science using the conjunction of the terms *aphasia*, *naming*, *distributed*, *practice*; *aphasia*, *naming*, *spacing*; *aphasia*, *naming*, *lag*; *aphasia*, *naming*, *schedule* returned 43 total articles. An additional search of PubMed of the same combinations of terms (constrained to appear in article abstracts, to focus the search on the most relevant articles) returned no additional articles. We screened the 43 articles for the following inclusion criterion: (a) included adults with aphasia as participants; (b) examined treatment focused on improving naming accuracy in aphasia; (c) controlled the type of treatment across conditions; and (d) examined spacing or lag effects in the scheduling of specific item trials or sessions of treatment while controlling for the number of trials per item across conditions. The reference lists of articles meeting these criteria were also examined for relevant articles. The articles returned in the search for the review of schedules of practice in other language treatments (see the "Distributed Practice Effects in Other Language Treatments of Aphasia" section) were also examined for possible inclusion here, and vice versa. One study (Morrow & Fridriksson, 2006) that examined two spaced schedules in naming treatment was rejected because whether lag differed between schedules was not examined or reported. Because the purpose of this article is to discuss verbal rather than motor skill learning, we excluded studies focused on speech–motor skills, such as treatment for apraxia of speech. Methodological details of the six studies meeting the inclusion criteria are given in Table 2.

Relevant to Principle 1 (see the "Distributed Practice Principles" section; Table 1), two studies have examined whether naming treatment benefits are enhanced when items are presented for spaced versus massed practice (Middleton et al., 2016, 2019). In addition, Middleton et al. (2016) examined whether increased lag between trials within a session further enhanced the benefits from spaced naming treatment (Principle 2). In that study, items were presented in a single treatment session for multiple trials of either retrieval practice or name repetition training to examine the effect of type of naming treatment on efficacy. Trials were either spaced or massed. In the massed schedule, one trial intervened between each of the trials for an item (massed condition was presented at a lag of 1, or lag 1). In the spaced schedules, 5, 15, or 30 trials intervened between each of the trials for an item (i.e., lag 5, lag 15, and lag 30). In group analyses on the four persons with aphasia

(PWA) studied, naming performance on retention tests administered 1 day and 1 week posttreatment was significantly higher for items in the spaced conditions than in the massed condition, constituting a spacing effect. A follow-up group analysis that statistically controlled for training accuracy suggested that increasing the lag of spaced trials (i.e., 5 to 15 to 30 trials) enhanced retention test performance for items trained with name retrieval practice, constituting a lag effect. Extending this work, Middleton et al. (2019) examined spacing effects when items were presented in a more clinic-inspired schedule of delivery. Four PWA completed retrieval practice or name repetition training for items according to a massed (lag 1) or spaced schedule (lag 24) in each of several treatment sessions. A group analysis on a retention test administered 1 week after the final treatment session showed a significant advantage for spaced versus massed practice. A similar trend was apparent at a retention test administered 1 month after the final session of treatment.

In a group study of nine PWA, Schuchard et al. (2019) examined effects relevant to Principles 3 and 4. In that study, six item sets per participant were assigned into six conditions formed by crossing a three-level factor of criterion level (Criterion 1, Criterion 2, Criterion 4, defined shortly) and a two-level factor of intersession lag (1-day lag phase and 7-day lag phase). In each of three sessions spaced 1 day apart (1-day lag phase) or 7 days apart (7-day lag phase), items were trained to their assigned criterion level (i.e., how many times an item was successfully retrieved in a session before it was dropped from additional training in that session). The study examined the effect of distributing an item's retrievals across sessions versus within a single session (Principle 3) by examining naming performance in a subsequent session for (a) items in the Criterion 1 condition trained in two prior sessions compared with items in the Criterion 2 condition trained in one prior session; and (b) items in the Criterion 2 condition trained in two prior sessions compared with items in the Criterion 4 condition trained in one prior session. The effects of the across- versus within-session factor were assessed at both 1-day (in the 1-day lag phase) and 7-day (in the 7-day lag phase) retention intervals.

Concerning the within- versus across-session comparisons (Principle 3), naming accuracy 1 or 7 days after training was 17–18 percentage points higher for Criterion 1 items trained in two prior sessions than for Criterion 2 items trained in one prior session. Similarly, naming accuracy 7 days after training was 21 percentage points higher for Criterion 2 items trained in two prior sessions than for Criterion 4 items trained in one prior session (the corresponding comparison in the 1-day lag phase unexpectedly showed no difference, possibly due to functional ceiling effects). In sum, spacing the same number of retrievals for an item across sessions versus concentrating the retrievals within a session generally conferred a robust increase in later naming accuracy. Because of the focus on equating number of correct retrievals in each comparison, the number of trials per item was not strictly controlled. However, the increase in total trials due to across-session spacing compared with within-session spacing was negligible.

To examine the effect of intersession lag (Principle 4), Schuchard et al. (2019) also administered a long-term retention test approximately 1 month after the final training session in each lag phase. A group analysis revealed a 5% advantage in naming accuracy for the 7-day lag phase over the 1-day lag phase ($p = .057$) at the 1-month long-term retention test. Six of the nine participants scored numerically higher on the long-term retention test in the 7-day lag phase than in the 1-day lag phase.

Three additional studies have tested the effect of intersession lag in naming treatment (Principle 4; Ramsberger & Marie, 2007; Raymer et al., 2006; Sage et al., 2011). Each of these studies administered two lag phases (shorter vs. longer lag), controlled for the number of trials per item and the number of sessions per lag condition, and counterbalanced the order of lag phase across participants.

Ramsberger and Marie (2007) studied four PWA, each completing two phases of treatment: a shorter lag phase administered five times per week, and a longer lag phase administered twice a week. Two participants completed 15 sessions per phase, and the two other participants completed 20 sessions per phase. Primary assessment of improvement in trained items involved multiple statistical indices comparing baseline performance with performance during treatment. Three of four PWA showed consistent benefit in both the shorter and longer lag conditions across all indices; the fourth PWA showed inconsistent benefit across indices for both conditions. However, as discussed in the "Distributed Practice Effects: Spacing and Lag" section, the distributed practice literature suggests that increases in lag generally enhance long-term retention rather than performance during training. Ramsberger and Marie (2007) collected three posttreatment probes for items trained in the shorter lag phase for two participants and for items trained in the longer lag phase for the other two participants. On the basis of participant-specific averages during treatment and posttreatment, only 85% and 43% of treatment benefits, were retained after the shorter lag phase; percentage of retained treatment benefits is calculated as follows: [1 – (treatment performance – posttreatment performance)/treatment performance]. In contrast, 98% and 106% of treatment benefits were retained after the longer lag phase, consistent with the expectation that longer lags confer more durable learning.[1]

Raymer et al. (2006) examined the effects of computerized word comprehension practice on naming performance, with treatment conducted in three to four sessions per week (shorter lag phase) or one to two sessions per week (longer lag phase). A 1-month posttreatment probe was administered after each phase. Primary treatment outcomes were assessed by comparing performance during treatment with baseline. Statistics focused on the standardized mean difference within each individual, an effect size calculation developed by Busk and Serlin (1992; for discussion, see Beeson & Robey, 2006). Standardized mean difference is problematic for a variety of reasons, including that it does not provide significance values and that effect size estimates can be inflated if there is little variability in the baseline probes (for discussion, see Lee & Cherney, 2018). With this caveat in mind, all five PWA showed strong effect sizes for trained items in the shorter lag condition, two PWA showed strong effect sizes, and two PWA showed moderate effect sizes for trained items in the longer lag condition. However, PWA on average retained 114% of treatment benefits at the 1-month test in the shorter lag condition but retained 150% benefits in the longer lag condition (i.e., performance tended to improve posttreatment, but more so in the longer lag condition).

In contrast to Raymer et al. (2006) and Ramsberger and Marie (2007), Sage et al. (2011) employed a more powerful manipulation of intersession lag by comparing naming therapy delivered five times per week for 2 weeks (shorter lag condition) versus one time per week for 10 weeks (longer lag condition). Naming performance was probed immediately after treatment and at 1 month posttreatment. Performance in the shorter and longer lag conditions was similar when probed immediately after treatment, but a significant advantage emerged for the longer lag condition at 1 month posttreatment. Thus, across the four studies reviewed, there is consistent evidence that greater intersession lag can confer more persistent retention of treatment benefits and superior long-term performance on trained items. In the "Literature Review Summaries and Clinical Implications" section, we provide a summary of the findings of the studies reviewed in this section and discuss their clinical implications.

[1]Values of percentage of retained treatment benefits that exceed 100 indicate performance was higher at follow-up compared than during treatment.

Distributed practice effects in other language treatments of aphasia

Other rehabilitation research in aphasia has examined how the distribution of treatment affects outcomes. Such studies have focused on therapies that address multiple language and communication goals and are seated within the larger literature on "treatment intensity" (for review, see Dignam, Rodriquez, & Copland, 2016). Intensive treatment has no standard definition but typically refers to large amounts of treatment administered over a relatively short duration, often involving long treatment sessions and short intersession lags. Some researchers have argued that an intensive treatment schedule is supported by neuroscience research at the cellular level (e.g., the Hebbian learning principle that neurons frequently active at the same time become more strongly connected) and by animal models showing that frequent, repetitive training leads to neurological change and functional improvement (e.g., Kleim & Jones, 2008; Pulvermüller & Berthier, 2008; Raymer et al., 2008). For people with aphasia, however, changes in neural activity and behavioral improvements occur following a wide variety of treatment schedules (for review, see Crinion & Leff, 2015). As examples, neurophysiological and behavioral changes in people with aphasia were demonstrated after participants received 10 or more hours of treatment per week (e.g., Fridriksson et al., 2007; Meinzer et al., 2004) as well as after more distributed schedules of three to four weekly hours with only two sessions per week (e.g., Sandberg, Bohland, & Kiran, 2015; Thompson, Riley, den Ouden, Meltzer-Asscher, & Lukic, 2013). It remains to be determined which patterns of neural activity are indicative of better language recovery and which treatment schedules may best promote those neural changes. With regard to behavioral improvement, it remains unclear whether an intensive treatment schedule promotes better outcomes than a more distributed schedule because the majority of relevant studies have compared intensive treatment with a period of no treatment or have failed to control the type or total amount of treatment across schedules (e.g., Bakheit et al., 2007; Barthel, Meinzer, Djundja, & Rockstroh, 2008; Berthier et al., 2014; Breitenstein et al., 2017; Hinckley & Carr, 2005; Hinckley & Craig, 1998; Pulvermüller et al., 2001). These studies show that intensive treatment is *effective*, but this type of schedule may or may not be *optimal*.

For our goal of examining the relevance of distributed practice principles to aphasia rehabilitation, the subset of studies in the intensity literature that have controlled the amount and type of therapy while manipulating intersession lag (Principle 4; see the "Distributed Practice Principles" section and Table 1) is most germane. Potential studies for review in this section were identified from literature searches conducted in March 2018. Searches on Web of Science using the conjunction of the terms *aphasia*, *treatment*, *intensity*; *aphasia*, *treatment*, *intensive*; *aphasia*, *massed*, *practice*; *aphasia*, *schedule*, *treatment* returned 337 articles. An additional search of PubMed of the same combinations of terms (constrained to appear in article abstracts, to focus the search on the most relevant articles) returned an additional eight articles. We screened the 345 total articles for the following inclusion criterion: (a) examined distributed versus intensive schedules in which the therapy addressed multiple aspects of language functioning; (b) included adults with aphasia as participants; (c) controlled the type of treatment across schedules; and (d) controlled the total amount of treatment defined in terms of number of total hours per schedule. The reference lists of articles meeting these criteria were also examined for relevant articles. Across studies, the number of sessions or the number of hours per session was not always controlled between schedules. Methodological details of these studies are given in Table 3.

Martins et al. (2013) employed a between-subjects design in which participants were randomly assigned to receive an intensive schedule of 5 days per week for 10 weeks (shorter lags) or a distributed schedule of one to two sessions per week for 50 weeks (longer lags) for a total of 100 hr of speech–language treatment. Language test batteries were administered at baseline and at 10, 50, and 62 weeks after the initiation of treatment for each group. The primary outcome was proportion of responders defined as individuals who showed a 15-point increase in aphasia quotient on the Aachen Aphasia Battery (Portuguese version, PAAT; Lauterbach et al., 2008) from baseline to the 50-week assessment. Secondary outcomes included mean change in aphasia quotient and functional communication measures and maintenance of benefits between the 50- and 62-week test points. Only 18 of the recruited 30 patients completed the study to the primary endpoint of 50 weeks (nine in each group), and 14 completed the study through the 62-week endpoint. The proportion of responders in the intensive treatment group (88%, or eight of nine participants) was not different from the proportion of responders in the distributed treatment group (78%, or seven of nine participants), and there were no group differences in the secondary outcomes. However, a limitation of the study is that the interval between the end of treatment and the primary endpoint was 40 weeks in the intensive group and no weeks in the distributed group. Important differences may have emerged at the primary or secondary endpoints if the retention interval had been controlled between groups. Nevertheless, although it is clear that participants in each type of schedule demonstrated meaningful change from treatment, there appeared to be no additional benefit from massing the treatment within a short time period.

In Harnish et al. (2008), one person with aphasia was administered treatment focusing on naming, sentence production, and written production first in an intensive treatment phase, followed by a distributed treatment phase. The intensive schedule involved five treatment sessions per week for 2 weeks and the distributed schedule involved two sessions per week for 7.5 weeks. The primary outcome was performance on the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983) administered at an unspecified interval after each treatment phase. The study reported numerically greater gains on the Boston Naming Test (i.e., three more items) over the first treatment phase (shorter lags) than in the second phase (longer lags). However, inferential statistics were not applied to test significant differences between the phases and the case study design precludes distinguishing the effects of treatment schedule from the effects of the order of the two conditions.

Mozeiko et al. (2016) delivered constraint-induced language therapy in an intensive or distributed schedule, with four participants per schedule. In the intensive schedule, participants engaged in 3-hr sessions 5 days a week for 2 weeks. In the distributed schedule, participants engaged in therapy 1 hr per session, 3 days a week for 10 weeks. The primary outcome was change in discourse production measures, with statistics focusing on participant-specific effect sizes of change from baseline to final probes during treatment (standardized mean difference; see the "Distributed Practice Effects in Naming Treatment of Aphasia" section for discussion of limitations of this approach). The small size of the participant groups ($n = 4$ per group) and treatment response heterogeneity rendered the results difficult to interpret. Some participants in both groups showed language improvements, but there were no clear differences in outcomes between the two schedules of treatment.

In Dignam et al. (2015), participants were nonrandomly assigned to an intensive or a distributed treatment schedule that involved a variety of types of treatments (e.g., word retrieval treatment; functional communication training; group therapy) but the same number of hours per type. In the intensive treatment schedule, 48 hr of treatment was administered over 3 weeks compared with 48 hr administered over 8 weeks in the distributed treatment schedule. Treatment outcomes were assessed immediately after treatment and after 1 month. On the primary outcome measure of naming ability measured by the Boston

Naming Test (Kaplan et al., 1983), the distributed group showed significantly greater improvement than the intensive group, both immediately after treatment and after 1 month. However, in a post hoc analysis of a subset of participants in Dignam et al. (2015), Dignam, Copland, et al. (2016) reported similar gains in the intensive and distributed groups in naming performance on items that were practiced during treatment as well as untreated items. Thus, the effect of schedule on generalized improvement on naming ability was inconsistent across the two studies. Finally, in Dignam et al. (2015), the intensive and distributed groups showed similar gains on ratings of functional communication, communication confidence, and communication-related quality of life.

Literature review summaries and clinical implications

We now briefly summarize the findings of the studies reviewed in the "Distributed Practice Effects in Naming Treatment of Aphasia" and "Distributed Practice Effects in Other Language Treatments of Aphasia" sections as they relate to the distributed practice principles (see the "Distributed Practice Principles" section; Table 1), and we consider clinical implications of the findings. Starting with the naming treatment literature (see the "Distributed Practice Effects in Naming Treatment of Aphasia" section), two studies reported spacing effects (Principle 1). After one session of training, Middleton et al. (2016) found that spaced presentation of items' trials compared with massed presentation enhanced naming accuracy 1 day and 1 week posttreatment. After four sessions of training, Middleton et al. (2019) found that spaced presentation of items' trials compared with massed presentation enhanced naming accuracy 1 week posttreatment, with a strong trend for a similar advantage at 1 month. Regarding Principle 2, Middleton et al. (2016) found that the benefits from retrieval practice naming training were enhanced when administered at longer lags within a session. One study (Schuchard et al., 2019) examined the benefit of administering the trials for items within a single session versus across sessions and found robust, superior performance after across-session training compared with within-session training (Principle 3). Thus, the results across studies support the recommendation for spaced rather than massed presentation, greater lag between items' trials within a session, and distribution of items' trials across multiple sessions rather than in a single session for robust and durable improvements in the naming of treated vocabulary in people with aphasia. It will be important in future work to examine possible boundary conditions to this recommendation. For example, future work could explore applicability of these principles to people with aphasia from across the range of severity of naming impairment and accompanying deficits (e.g., executive control dysfunction; apraxia of speech) or to treatment targets of other types (e.g., verbs; modified noun phrases).

Regarding Principle 4, four naming treatment studies manipulated the lag between sessions (intersession lag). A relatively restricted range of lags was contrasted in Ramsberger and Marie (2007; i.e., two vs. five sessions per week) and in Raymer et al. (2006; i.e., one to two sessions per week vs. three to four sessions per week). These two studies showed little difference between the two conditions in terms of performance attained during treatment, whereas there were patterns of retention consistent with more persistent benefits for the longer lag condition. Using a more powerful manipulation of lag (i.e., 1 vs. 7 days), Sage et al. (2011) found a significant advantage of longer versus shorter intersession lag at follow-up, and Schuchard et al. (2019) found a trend bordering on statistical significance favoring the longer intersession lag condition after 1 month.

Thus, effects of intersession lag were not consistently documented across the reviewed naming treatment studies. However, the psychological literature suggests the benefits of increasing lag are generally more apparent after training rather than during acquisition (e.g., Cepeda et al., 2006). It will be important in future treatment studies examining the effects of intersession lag to examine performance on a final retention test administered after a delay as a primary outcome (e.g., Sage et al., 2011; Schuchard et al., 2019) as opposed to focusing on performance during treatment as in Ramsberger and Marie (2007) and Raymer et al. (2006). A broader implication of the timing of measurement of distributed practice effects for clinical practice relates to a pervasive focus by clinicians and insurers on performance during treatment sessions. People with aphasia may be better served by schedules and methods of treatment that lead to suboptimal performance during treatment in order to capitalize on distributed practice principles for maximizing sustained, long-term improvements.

In the review of studies of other language treatments in the intensity literature (see the "Distributed Practice Effects in Other Language Treatments of Aphasia" section), four studies examined outcomes after treatment that was delivered with shorter versus longer intersession lags (Principle 4). In Martins et al. (2013), Harnish et al. (2008), and Mozeiko et al. (2016), there was little difference in outcomes following shorter versus longer intersession lags. However, each study exhibited limitations such as low numbers of observations contributing to key statistical contrasts and failure to equate retention intervals between groups (Martins et al.), possibility of order effects (Harnish et al.), and interpretational difficulties that accompany the use of single-case statistical indices (Harnish et al.; Mozeiko et al.; see the "Distributed Practice Effects in Naming Treatment of Aphasia" section). Dignam et al. (2015) reported a significant advantage in their primary outcome (naming performance) after treatment delivered with longer compared with shorter intersession lags immediately after posttreatment and at follow-up. However, there was little difference between schedules regarding secondary outcomes and a post hoc analysis of naming performance for items administered for treatment and untreated items reflected no effect of schedule (Dignam et al., 2015). In summary, the review of other language treatment studies provided no evidence to suggest that longer treatment sessions and shorter intersession lags were more efficacious than shorter sessions and longer intersession lags.

Regarding the issue of intersession lag for either naming or other language treatment, a pragmatic consideration may be that if more distributed treatment schedules are at least equally effective as the minimized spacing of intensive schedules, then clinicians and patients could avoid the fatigue and other difficulties that clinicians have reported to be associated with the implementation of high-intensity aphasia treatment (Gunning et al., 2017). An additional pragmatic consideration regarding intersession lag concerns the defined time frame of delivery of speech–language treatment. For example, if insurance providers define time in therapy as a limited term (e.g., 3 months), more therapy sessions at the expense of shorter intersession lags are probably to be preferred for maximizing treatment gains. If, however, limits are set on the number of sessions, the clinician may as well spread out the sessions over a longer period of time because none of the controlled studies we reviewed reported a cost in doing so.

FUTURE DIRECTIONS

Research on formal application of principles of distributed practice to aphasia treatment is in its infancy. There is a great need for further research to advance an understanding of the full clinical applicability of distributed practice principles to the treatment of aphasia. One important goal in future research may be to examine whether distributed practice principles have implications for generalized performance (e.g., to untrained items; to overlapping but nonidentical processes). Interestingly, there is an emerging literature showing that distributed practice manipulations can increase generalization defined as abstraction across learning events and application to new contexts. Such effects have been found in the learning of scientific concepts (e.g., Gluckman, Vlach, & Sandhofer, 2014) and natural categories (e.g., Wahlheim, Dunlosky, & Jacoby, 2011) as well as mathematical problem-solving (e.g., Hopkins, Lyle, Hieb, & Ralston, 2016). In light of these findings, productive lines of aphasia research may involve examination of whether applying distributed practice principles enhances generalization in language abilities in aphasia, particularly in forms of treatment that show theoretically grounded and robust generalization (e.g., Des Roches et al., 2016; Kiran, 2008; Thompson, Shapiro, Kiran, & Sobecks, 2003).

It will also be important in future work to delineate how distributed practice principles impact language-based processes/representations specifically, as the preponderance of distributed practice studies has focused on novel knowledge or skill acquisition. Some studies in this review (e.g., Middleton et al., 2016, 2019; Schuchard et al., 2019) have found applicability of distributed practice principles to lexical access for premorbid vocabulary in aphasia. Additional findings in the distributed practice literature point to relevance to language, such as observations of benefits of distributed practice for the learning of grammatical rules in neurotypical speakers (Bird, 2010; Miles, 2014).

Finally, it will be important in studies on intensity of treatment to consider distributed practice principles when designing future experiments or trials. Such studies should equate the amount of treatment across schedules, hold the type of treatment constant, and also contrast intersession lags of greater difference than has typically been done. It may also be prudent to consider treatment designs that capitalize on methods that produce high-impact learning effects in the distributed practice literature. For example, although few in number, cognitive psychology studies that tested participants multiple months after training suggest that implementing a long lag (e.g., 1 month or longer) between initial training and at least one retraining session promotes the maintenance of gains over long retention intervals (Bahrick et al., 1993; Carpenter, Pashler, & Cepeda, 2009; Cepeda et al., 2008, 2009), which is an important goal in applied training settings. A possible treatment strategy in line with these findings would be the addition of at least one "refresher" session administered at a long lag after the initial period of treatment to promote long-term maintenance of gains. In addition, as demonstrated in neurotypical learners (e.g., Rawson et al., 2018; Vaughn et al., 2016) and shown to hold in aphasia (Schuchard et al., 2019), increasing the number of sessions spaced over time strongly enhances learning whereas increasing the amount of training within the initial training session has relatively weak effects. If similar principles apply to naming or other types of language treatment, language recovery could be enhanced by distributing the amount of treatment dedicated to a specific item or a specific training exercise over more sessions on separate days. Research designed to test these new directions has strong potential to promote persistent learning of trained words, and possibly maximize recovery in other language domains, for people with aphasia.

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