

2-13-2023

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Errorless, Errorful, and Retrieval Practice for naming treatment in aphasia: A scoping review of learning mechanisms and treatment ingredients

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Conflicts of Interest: The authors have no relevant conflicts of interest to disclose.

Funding Statement: Some of the work reported in this manuscript was supported by the National Institute on Deafness and Other Communication Disorders of the National Institute of Health under award numbers R21DC019203 and R01DC015516. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute of Health.

Data Availability Statement: The data collected in this scoping review is available from the corresponding author on reasonable request.

Abstract

Purpose: Increasingly, mechanisms of learning are being considered during aphasia rehabilitation. Well-characterized learning mechanisms can inform *how* interventions should be administered to maximize the acquisition and retention of treatment gains. This systematic scoping review mapped hypothesized mechanisms of action (MoAs) and treatment ingredients in three learning-based approaches targeting naming in aphasia: errorless learning (ELess), errorful learning (EFul), and retrieval practice (RP). The rehabilitation treatment specification system (RTSS) was leveraged to describe available literature and identify knowledge gaps within a unified framework.

Method: PubMed and CINHAL were searched for studies that compared ELess, EFul, and/or RP for naming in aphasia. Independent reviewers extracted data on proposed MoAs, treatment ingredients, and outcomes.

Results: Twelve studies compared ELess and EFul, six studies compared ELess and RP, and one study compared RP and EFul. Hebbian learning, gated-Hebbian learning, effortful retrieval, and models of incremental learning via lexical access were proposed as MoAs. To maximize treatment outcomes within theorized MoAs, researchers manipulated study ingredients including cues, scheduling, and feedback. Outcomes in comparative effectiveness studies were examined to identify ingredients that may influence learning. Individual-level variables, such as cognitive and linguistic abilities, may affect treatment response; however, findings were inconsistent across studies.

Conclusion: Significant knowledge gaps were identified and include (1) which MoA(s) operate during ELess, EFul, and RP and (2) which ingredients are active and engage specific MoAs, and (3) how individual-level variables may drive treatment administration. Theory-driven research can

support or refute MoAs and active ingredients enabling clinicians to modify treatments within theoretical frameworks.

1. Introduction

In cognitive neurorehabilitation, theories of learning can advance clinical practice by elucidating *how* treatments can be administered and *to whom* to confer durable change to treated systems (Baddeley, 1993; Maas et al., 2008; Maier et al., 2019; Middleton et al., 2016, 2020; Stark, 2005; Vallila-Rohter, 2017). The learning mechanisms underlying aphasia interventions are underspecified or not consistently identified. Thus, clinicians may have difficulty making informed decisions about which treatment elements are essential for learning and whether a treatment is appropriate considering a client's language *and* learning profile. Minor variations in therapy administration that are common to aphasia treatment (e.g., opportunity to make errors, effort of retrieval, feedback) can have a profound influence on how learning unfolds and how information is retained. Minor manipulations to learning tasks have been found to affect learning in educational contexts and psychology (Karpicke, 2017; Kornell et al., 2009; Pashler et al., 2005; Rawson & Dunlosky, 2011) as well as in clinical populations including individuals with amnesia (Clare & Jones, 2008), Parkinson's disease (Foerde & Shohamy, 2011; Kearney et al., 2019), Korsakoff's syndrome (Komatsu et al., 2000), multiple sclerosis (Chiaravalloti & DeLuca, 2002; de Lima et al., 2020; Sumowski et al., 2010), and traumatic brain injury (Ownsworth et al., 2017; Sumowski et al., 2014).

Task manipulations that influence error-rate and participant effort have been applied to neurorehabilitation within three learning-based approaches: errorless learning (ELess), errorful learning (EFul) and retrieval practice (RP). Historically, ELess has been evaluated as an alternative to traditional trial-and-error approaches (i.e., EFul) to minimize error-learning (for review see

Clare & Jones, 2008; Middleton & Schwartz, 2012). ELess was formally considered in aphasia by Fillingham et al. (2003) who proposed that ELess would maximize opportunities for individuals to produce the correct name in the presence of a target object resulting in superior naming outcomes relative to Eful. In aphasia, ELess naming treatment typically involves repeated correct stimulus-response association, often through repetition practice while Eful takes the form of confrontation naming with little or no support to control for errors (see Figure 1). Ultimately, comparisons of ELess and Eful aim to elucidate whether the incidence of errors influences learning outcomes.

[Figure 1 near here]

Interest in RP as a training technique developed apart from research on ELess and Eful. RP was investigated in education and psychology research as a potent method for modifying memory and acquiring knowledge (for reviews see Karpicke, 2017; Rowland, 2014). Middleton et al. (2015) adapted the standard RP paradigm to a naming treatment for aphasia and hypothesized that Eful and ELess fail to prioritize training experiences of highest value in the RP literature—effortful yet successful retrieval (Middleton & Schwartz, 2012). In RP for aphasia, researchers provide a familiarization trial (typically in the form of repetition practice) followed by retrieval attempts that are spaced over time (see Figure 1). Comparisons of ELess and RP aim to evaluate successful naming opportunities with low effort (repetition of a word) and high effort (retrieval of a word from long-term memory) to determine whether learning is enhanced when naming is effortful and successful.

ELess, Eful, and RP have been evaluated in aphasia primarily within studies contrasting two of these broadly defined learning approaches. Within the past decade, rehabilitation research has moved towards well-defined treatment theories which drive research with the goal of

evaluating (1) the mechanisms hypothesized to grant change to a treated system and (2) the actions executed by the clinician that engage mechanisms. Well-specified treatment theories allow clinicians to identify the mechanisms that may motivate prioritizing certain treatment ingredients for a particular client.

The Rehabilitation Treatment Specification System (RTSS) offers a means to increase the specification of treatment ingredients and learning mechanisms within a unified framework (Hart et al., 2014, 2018). The RTSS was developed by an interdisciplinary group of clinician-scientists and identifies three core components of treatment theory: targets, ingredients, and mechanism(s) of action (MoA). *Targets* refer to measurable aspects of function or behavior expected to improve as a result of treatment. *Ingredients* refer to actions carried out by the clinician while *active ingredients* are those actions thought to produce change in the target. Ingredients are further broken down into those that target treatment groups (e.g., organ functions, skills and habits, and internal representations) or client volition. *MoAs* are hypotheses of how ingredients induce change in specified targets. Work in aphasia rehabilitation is beginning to adopt the RTSS and apply the framework to explain evidence-based interventions (Basilakos et al., 2022; Boyle et al., 2022; Cherney et al., 2022; Fridriksson et al., 2022). Boyle et al. (2022) note that a useful next step to improve the clarity with which clinicians and researchers characterize aphasia treatments would be to apply the RTSS within systematic review studies. Applying the RTSS to ELess, EFull, and RP, as we aim to do, can clarify the effects of variation in treatment administration, characterize proposed MoAs across studies, and evaluate gaps in research such as potential active ingredients warranting further exploration. Additionally, the current scoping review will allow for integration of more than a decade of research that has been conducted since the most recent reviews of ELess

in aphasia (Fillingham et al., 2003; Middleton & Schwartz, 2012). Uniquely, this review is the first to jointly evaluate ELess, Eful, and RP for naming in aphasia.

Given the potential utility of considering learning mechanisms in aphasia rehabilitation, the current scoping review aims to describe proposed MoAs and treatment ingredients in ELess, Eful, and RP interventions for naming in aphasia. Scoping reviews provide a means to identify and map existing evidence (Arksey & O'Malley, 2005) with the *intended goals* of (a) clarifying key concepts and factors related to a research topic, (b) outlining how research has been conducted in a topic area, and (c) identifying gaps within the current research (Munn et al., 2018). Our aims align with these goals and are as follows: for ELess, Eful, and RP targeting naming in aphasia,

- (1) Describe the hypothesized MoAs (*intended goal a*, see Results, section 3.b.)
- (2) Outline treatment ingredients (*intended goal b*, see Results, section 3.c.)
- (3) Consider treatment ingredients in the context of comparative effectiveness outcomes to identify ingredients that may warrant further exploration (*intended goal a*, see Results, section 3.d.)
- (4) Identify gaps in the current knowledge base (*intended goal c*, see Discussion, section 4)

2. Method

2.a. Search Strategy and Selection of Sources of Evidence

PubMed, CINHAL, and opendissertations were searched for studies published before January 2022 using the key terms: (“errorless learning” OR “errorless” OR “decreasing cues” OR “decreasing cue” OR “errorful learning” OR “errorful” OR “increasing cues” OR “increasing cue” OR “retrieval practice” OR “testing effect” OR “spaced retrieval” OR “progressive cueing” OR “progressive cues” OR “cue hierarchy” OR “cue hierarchies” OR “cueing hierarchy”) AND

(aphasia OR “Aphasia”[Mesh] OR anomia OR “Anomia” [Mesh]). Subject headings “Aphasia +” and “Anomia” were used to search CINHALL and opendissertations. Additional studies were identified through paper references. All identified studies were imported to Covidence (*Covidence Systematic Review Software*, n.d.). Abstract and full-text screening were performed by two independent reviewers (KN & a graduate research assistant). Reviewers met prior to initiating the screening process to ensure mutual understanding of the inclusionary criteria. The inclusionary criteria are as follows: (1) population was people with aphasia; (2) target of treatment was naming; (3) compared at least two of the following: ELess, EFull, RP; (4) study analyzed original data. Any disagreements were resolved via discussion and consensus between the two reviewers. If a consensus could not be reached, a third reviewer (SVR) assisted in making the final decision.

2.b. Data Extraction

Data extraction was performed by two independent reviewers (KN and SVR) using an electronic form developed by KN. All disagreements between the reviewers were resolved via discussion and consensus. After data extraction, the first author summarized the data and shared it with the co-authors who alerted the first author to information that required clarification. Data were collected on: (1) interventions compared, (2) proposed MoAs, (3) cues, (4) feedback, (5) treatment design and schedule, (6) number of treatment items, (7) naming attempts per session, and (8) error-rates. Data extraction aimed to characterize minor variations in treatment ingredients that may influence learning (e.g., corrective vs. informative feedback). Variables for which data were sought are defined below:

- (1) Cue type: Cues were defined as the amount of phonemic, orthographic, or semantic information provided by the clinician (e.g., spoken and written word, word initial cues).
When cues were provided within a cue hierarchy, they were defined by both (a) the cue

direction and (b) when movement along the cue hierarchy occurred. Cue direction: *Decreasing*: most informative to least informative cueing. *Increasing*: least informative to most informative cueing. When movement occurred: *Within trial*: Movement along the cueing hierarchy occurs within a single trial. *Across sessions*: Movement along the cueing hierarchy occurs across sessions.

(2) Feedback: *Implied corrective*: accuracy conveyed through trial advancement or movement along the cueing hierarchy. *Explicit corrective*: accuracy conveyed verbally. *Informative*: participant provided with the correct response.

(3) Treatment design: *Parallel*: interventions administered in separate blocks within the same session. *Alternating*: interventions are administered in alternation across sessions or weeks. *Sequential*: training of one condition completed before training of subsequent condition. *Interleaved*: interventions administered in the same block within the same session.

(4) Items: number of items targeted within a cycle of training per condition.

(5) Schedule: frequency and duration of training.

(6) Naming attempts: number of naming attempts per item per session.

(7) Error rates: Proportion of accurate responses during training. If error rates could not be calculated by data provided within the paper, they were extracted from figures using WebplotDigitizer (Version 4.5; Rohatgi, 2020). Error rates could not be estimated in all papers; however, these papers were included in the scoping review. Error rate data was extracted to determine if participants made more errors in ELess relative to EFull training.

To minimize the risk of bias when synthesizing results and contextualize comparative effectiveness statements (Boyle et al., 2022), data on outcomes and analysis methods were extracted and are included in Table 1. Data were collected on the following:

- (1) Level of analysis (single case, multiple case, group).
- (2) Timing of testing (e.g., 1 week, 1 month, etc.).
- (3) Comparative effectiveness as stated by authors.
- (4) Dependent variable used to assess outcomes (e.g., number of trained items named accurately, difference scores between pre- and post- treatment probes of trained items).
- (5) Statistical methods applied (e.g., None, chi-squared test, ANOVA, etc.).
- (6) Correction for multiple comparisons, when applicable.

A scoping review protocol was drafted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) (Tricco et al., 2018). As scoping reviews allow for changes to the protocol given sufficient justification, the following changes were made to the unregistered review plan:

- (1) Data on outcomes and analysis methods were not collected for studies where authors reported more errors during ELess relative to EFull training as this is a minimally necessary criterion for a treatment to be considered 'errorless' or 'errorful'. Inclusion of these studies in the outcomes section may confound conclusions drawn.
- (2) Data on dependent variables used to assess outcomes was collected to provide context for comparative effectiveness statements.
- (3) Decreasing and increasing cue hierarchies were considered as ELess and EFull, respectively. Historically, decreasing cue hierarchies were used in the first application of ELess techniques to neurorehabilitation (Glisky et al., 1986). In naming treatment for aphasia, cue hierarchies have been used to compare outcomes following training with low and high error-rates.

3. Results

3.a. Sources of Evidence

A total of 84 unique studies were screened. After screening, 21 papers advanced to the full-text review. Two studies were excluded during the full-text review. Conroy (2008) was a dissertation of later published research and Lambon Ralph et al. (2010) amalgamated data from other included papers. Data extraction was performed with 19 studies all of which were included. One study (Thomas et al., 2012) was removed from the comparative effectiveness data extraction because the participant produced more errors during ELess compared to EFull training. Twelve studies compared ELess and EFull (Abel et al., 2005, 2007; Choe et al., 2017; Conroy et al., 2009a, 2009b; Fillingham et al., 2005a, 2005b, 2006; Lacey, 2010; Lacey et al., 2004; McKissock & Ward, 2007; Thomas et al., 2012), six studies compared ELess and RP (Friedman et al., 2017; Middleton et al., 2015, 2016, 2019; Schuchard & Middleton, 2018a, 2018b), and one study compared RP and EFull (Fridriksson et al., 2005).

[Figure 2 near here]

3.b. Description of Mechanisms of Action Proposed in Reviewed Studies (Aim 1)

MoAs were proposed or referenced by authors; however, studies typically did not seek to confirm a particular MoA. In some instances, studies attributed a theoretical framework describing an MoA to other researchers but did not espouse it as the definitive explanation (e.g., Middleton et al., 2015, 2016 and Hebbian learning for ELess). Additionally, in some instances, authors reported that findings were not consistent with the proposed MoAs (e.g., Lacey, 2010) suggesting that alternative mechanisms may be responsible for the treatment effect. Learning mechanisms are not mutually exclusive and may be best applied under specific learning contexts and with certain learners.

3.b.1. Errorless Learning. ELess prioritizes accurate naming of targets. Nine studies (Choe et al., 2017; Conroy et al., 2009b; Fillingham et al., 2005b, 2006; Lacey et al., 2004; Lacey, 2010; McKissock & Ward, 2007; Middleton et al., 2015, 2016) acknowledged Hebbian learning as an MoA that has been proposed for ELess. Hebb (1949) posited that repeated patterns of neuronal firing between cells strengthen the relationship and efficiency of firing between the involved cells. The implication is that if a stimulus elicits a response, the likelihood of making that response again, given the stimulus, increases. In purely Hebbian learning in which there is no error correction, the strengthening of the relationship between the stimulus and response occurs regardless of response accuracy (Fillingham et al., 2003).

Models of lexical access have been applied to explain learning under ELess naming treatment in five studies (Abel et al., 2005, 2007; Middleton et al., 2019; Schuchard & Middleton, 2018a, 2018b). Abel et al. (2005, 2007) applied the weight-decay model of lexical access (see Dell et al., 1997) to ELess and EFull. However, they found that a semantic-phonological model of lexical access better aligned with treatment response. Semantic-phonological models of lexical access have been considered more recently as MoAs in ELess and RP by Schuchard et al. (2018a, 2018b) and Middleton et al. (2019) and will be discussed in section 3.b.3. Four studies (Conroy et al., 2009a; Fillingham et al., 2005a; Friedman et al., 2017; Thomas et al., 2012) did not explicitly cite a learning mechanism in ELess.

3.b.2. Errorful Learning. In EFull, naming effort is prioritized over naming success. Four studies (Choe et al., 2017; Fillingham et al., 2005b, 2006; McKissock & Ward, 2007) have identified Hebbian learning with a monitoring system that filters out incorrect responses as a potential MoA (i.e., gated-Hebbian learning). To prevent Hebbian learning mechanisms from reinforcing incorrect stimulus-response associations, during the learning process, incorrect and

correct responses must be differentiated. Lambon Ralph and Fillingham (2007) describe this process as a gating mechanism thought to comprise three components: a) detection of errant behavior, b) memory/coding of responses and stimuli, and c) attentional-executive skills for gating learning or correcting errors. When an error is detected, the gating mechanism is hypothesized to halt learning or an error-correcting mechanism reinforces the correct response over the error (Lambon Ralph & Fillingham, 2007; see McClelland et al., 1999). When gating mechanisms are intact, Lambon Ralph and Fillingham (2007) propose that Eful is as effective as Eless. When any of the gating mechanisms are faulty, in the instance of an error, Hebbian learning may proceed, and errors risk being reinforced.

Three studies (Conroy et al., 2009a; Lacey et al., 2004; Lacey, 2010) identified effort as a task element essential to Eful. Effort can be driven by inherent task demands and/or client engagement (Conroy et al., 2009a; McKissock et al., 2007). Research that considers naming effort suggests that treatment ingredients that promote effortful naming provide more active engagement in the treatment process resulting in superior attention and memory encoding (Lacey, 2010; see Robertson & Murre, 1999). The RP literature also outlines how effort can produce long-lasting change to a memory trace and will be discussed. Four studies (Conroy et al. 2009b; Fillingham et al., 2005a; Fridriksson et al., 2005; Thomas et al., 2012) do not cite an MoA for Eful.

3.b.3. Retrieval Practice. RP aims to achieve a balance between effortful and successful naming. In education and psychology research, there are several theories regarding the mechanisms that result in the advantage of RP over restudy (for review, see Karpicke, 2017). The RP literature in aphasia acknowledges many of these potential mechanisms (e.g., mediator effectiveness hypothesis, elaborative retrieval hypothesis) yet two mechanisms are consistently discussed.

Three studies (Friedman et al., 2017; Middleton et al., 2015, 2016) discuss effortful retrieval as a conceivable MoA underlying RP. Bjork and Bjork (1992) propose that memories have a storage strength and a retrieval strength. Storage strength is the persistent strength of an internal representation. Retrieval strength is the accessibility of an internal representation at a given time. When retrieval strength is low, retrieval is more effortful and storage strength is increased to a greater degree than when retrieval strength is high. This framework implies that for maximal learning, RP should be ‘desirably difficult’ (Bjork, 1994), i.e., effortful to the point of maximal difficulty while still being successful.

RP for anomia has also been described within theories of lexical access in four studies (Fridriksson et al., 2005; Middleton et al., 2019; Schuchard & Middleton, 2018a, 2018b). Most notably, Schuchard and Middleton (2018a, 2018b) hypothesized that an incremental learning mechanism confers changes to each of the two main stages of lexical access as outlined in the two-stage interactive model of lexical access (Dell et al., 1997; Schwartz et al., 2006). In that model, in the first stage, a target word is selected from a cohort of co-activated words that are related to the target, which corresponds to mapping from semantics to words across weighted connections (*s-weights*). In the second stage, the retrieved word is mapped to its constituent phonemes via *p-weights*. To model naming impairment in aphasia, the s- or p-weights are reduced to heighten competition at that level, leading to naming errors (primarily word-retrieval errors, e.g., horse for zebra, at stage-1 and phonological errors, e.g., deeber for zebra, at stage-2). Schuchard and Middleton (2018a, 2018b) hypothesized that repetition-based ELess should primarily strengthen stage-2 because the target word can be directly activated from input phonology (Nozari et al., 2010), and thus retrieval from semantics is not required. In contrast, RP should strengthen both stages because naming during RP requires, and thus engages, stage-1 and stage-2.

3.b.4. Summary. Authors have hypothesized that treatment effects may be accounted for by the following MoAs: (1) Errorless learning: Hebbian learning and incremental learning via lexical access, (2) Errorful learning: gated-Hebbian learning, effortful retrieval, and (3) Retrieval practice: effortful retrieval, incremental learning via lexical access.

3.c. Outline of Treatment Ingredients (Aim 2)

Table 1 summarizes extracted study ingredients. Cueing was the primary ingredient used to differentiate between ELess, Eful, and RP. In ELess, cues act as the ingredient intended to promote successful target production. The primary ingredient differentiating Eful and RP was a maximally cued naming trial via repetition (i.e., familiarization trial) before un-cued or cued naming/retrieval. In RP, but not Eful, retrieval attempts were preceded by a familiarization trial that aimed to maintain participant effort while maximizing retrieval success. RP studies were also more consistent in the provision of feedback across studies.

[Table 1 near here]

Feedback provision varied across studies (see Table 1). Most studies specified whether feedback was provided and what information was conveyed by feedback (i.e., accuracy, correct response). Informative feedback was typically in the form of a repetition trial which could be considered an additional trial of repetition practice. Five RP studies provided feedback after the 8s naming trial which may result in a delay between participant response and feedback. The timing of feedback may be a variable of interest given that it can influence the neural systems recruited for learning (e.g., Foerde & Shohamy, 2011).

Intensity can be measured with the number of sessions a week, number of weeks of therapy, number of naming attempts per target per session, and number of items trained. The most frequent intensity of intervention was twice a week for five weeks. Four of six studies comparing ELess to

RP trained targets in a single session to eliminate confounds related to spacing across multiple sessions limiting generalization to treatment which occurs over more than one session. The number of items trained per condition ranged from 10 to 288. RP studies tended to train more items, although this ingredient was likely used to achieve sufficient power with small sample sizes.

The ingredients in Thomas et al. (2012) resulted in the participant producing more errors during ELess relative to EFull training. Examination of the treatment ingredients may elucidate techniques that do not produce the desired error-rates in training. However, the methods of Thomas et al., 2012 were comparable to other studies and modeled after Abel et al. (2005) (see Table 1). Differences in training may be a consequence of the participant's cognitive or linguistic impairment profile or methodological differences not stated in text (e.g., training sets not balanced for difficulty).

3.d. Description of Ingredients in the Context of Comparative Effectiveness Studies (Aim 3)

This section first outlines the general comparative effectiveness of ELess, EFull, and RP as reported by the authors of the reviewed studies (see Table 1). Then, studies that vary in their outcomes are compared to gain insight into ingredients that may influence treatment response.

3.d.1. Errorless and Errorful Learning. Several studies reported comparable results between ELess and EFull conditions at immediate and follow-up testing intervals (Abel et al., 2007; Choe et al., 2017; Conroy et al., 2009a; Fillingham et al., 2005a, 2005b, 2006; Lacey, 2010). However, in at least one instance of testing, Lacey et al. (2004) and Abel et al. (2005) found an EFull advantage while McKissock et al. (2007) and Conroy et al. (2009b) found an ELess advantage. A small subset of individual participants demonstrated a significant advantage for EFull ($n = 2$, Fillingham et al., 2006, $n = 1$, Lacey, 2010) or ELess ($n = 1$, Conroy et al., 2009b).

Studies with divergent findings may provide insight into active ingredients. Conroy et al. (2009a, 2009b) studied some of the same participants yet one study (2009b) showed a marginal ELess over EFull advantage whereas the other (2009a) did not. The primary methodological difference was the structure of cues. ELess consisted of repetition practice in Conroy et al., 2009b and a decreasing cue hierarchy in Conroy et al., 2009a. In the EFull condition, Conroy et al. (2009a) utilized a staircase method of cueing such that after a correct response was produced by a person with aphasia, cues were reduced/increased until five naming attempts (correct or incorrect) were made for each target. In Conroy et al. (2009b), once an item was named correctly in an increasing cues trial, the target was repeated to achieve five naming attempts. How cues were organized and subsequent naming attempts elicited may have led to an increase in errors or reduced instances of effortful naming ultimately influencing treatment response across studies.

Ingredients to modify the effort of naming were also evaluated by Lacey et al. (2004) who trialed two different ELess training conditions after noticing a plateau in response to ELess training. Positing that movement along the decreasing cue hierarchy within a single trial resulted in reduced effort during naming, they integrated a spaced retrieval design into the ELess conditions such that targets were trained in pairs. Thus, movement along the decreasing cue hierarchy for a single target was separated by training of the pair word. Results of only two probe sessions are reported in the manuscript but reveal equivalent gains under ELess and EFull training conditions only when manipulations were incorporated to maintain participant effort via spacing. In a follow-up study, Lacey (2010) employed a spaced design in the ELess and EFull conditions. A clear advantage for spaced ELess or EFull was not found. However, a greater proportion of participants maintained gains in EFull ($n = 6$) compared to ELess ($n = 2$) at the 6-month follow-up assessment.

Feedback has been considered as a critical ingredient in Eful. McKissock et al. (2007) observed an advantage of Eful with explicit corrective and informative feedback over Eful without feedback. In addition, except for Conroy et al. (2009b), those studies that provided implied feedback in the Eful condition led to the most consistent Eful over Eless advantages at the individual subject level (Abel et al., 2005; Fillingham et al., 2006; Lacey et al., 2004; Lacey, 2010). However, some studies report that feedback is not a key ingredient during Eful (Fillingham et al., 2005b). Fillingham et al. (2005b) considered outcomes in two separate studies: one with implied feedback (Fillingham et al., 2006) and one without feedback (Fillingham et al., 2005b) during Eful. In both studies, Eless and Eful outcomes were equivalent leading authors to suggest that feedback did not influence treatment response. These studies draw into question the role of feedback and potentially, how variation in feedback (e.g., explicit, implied) may influence learning.

Reviewed studies were not sufficiently consistent in their description of intensity parameters to compare outcomes as they relate to dosage, intensity, and frequency of treatment, though these are factors that may influence outcomes. Fillingham et al. (2005a) and (2005b) utilized similar methods and participants but differed in the number of naming attempts per trial (9/session and 3/session, respectively). A larger number of participants in the 2005b study showed no improvement ($n = 5$) from either Eless or Eful interventions at follow-up testing five weeks after training compared to the 2005a study ($n = 1$), suggesting that increased naming attempts may contribute to retention of treatment gains.

3.b.2. Errorless Learning and Retrieval Practice. At retention and follow-up intervals, RP outperforms Eless (Friedman et al., 2017; Middleton et al., 2015, 2016, 2019) except for studies that examine these interventions as they relate to impaired naming at semantic versus

phonological levels (Schuchard & Middleton, 2018a, 2018b). RP was more effective than ELess for improving later naming performance in a person with aphasia with a word retrieval deficit (stage-1 mapping impairment), whereas a second person with aphasia with a stage-2 mapping impairment benefitted similarly from the two treatment approaches (Schuchard & Middleton, 2018b). Likewise, in a group study of 10 people with aphasia, RP was more effective than ELess at improving performance on items that elicited naming errors attributable to stage-1 (e.g., semantic errors) and not stage-2 (e.g., phonological errors) mapping failure (Schuchard & Middleton, 2018a). These findings are consistent with incremental learning via lexical access as an active MoA in retrieval and repetition-based naming treatments.

The spacing of repeated training trials was examined as a variable that may influence naming effort. Middleton et al. (2016, 2019) administered RP and ELess both for massed practice (items separated by one intervening trial) and spaced practice (items separated by multiple intervening trials). In both studies, when collapsed across RP and ELess conditions, spaced practice produced greater learning than massed practice. Middleton et al. (2016) suggested that during RP, spaced learning increases retrieval effort and ultimately, long-term retention of gains – as is found in many types of learning (for review see Carpenter et al., 2012).

Ingredients that promote successful retrieval may influence outcomes in RP. Middleton et al. (2019) for example, noted that the one of four participants did not show an advantage of RP over ELess. This participant was the most severely impaired and produced more errors relative to other participants during RP training. Similarly, Middleton et al. (2015) found that ingredients that promoted successful naming were beneficial to retention. The RP advantage over ELess was maintained longer for cued compared to uncued RP (Middleton et al., 2015). Authors proposed

that these findings support the hypothesis that RP benefits are tied to successful retrieval in addition to effort.

Additional training after an item has been learned may influence outcomes differently for RP and ELess. Friedman et al. (2017) examined ‘overlearning’, specifically, how additional ELess (called study trials) or RP trials influenced retention after a target was learned (named twice on two consecutive initial test trials). At 1 and 4 months post-treatment, items that were over-tested (RP) were retained better than items that were over-studied (ELess). When comparing over-tested and over-studied items to items that were dropped from further training once learned, only over-tested (RP) items benefitted from additional training at 1 and 4 months post-treatment. This work suggests that continued ELess via repetition practice once a target is learned may not confer additional benefits to the language system while additional RP may.

3.b.3. Retrieval Practice and Errorful Learning. Only one study evaluated the comparative effectiveness of RP and Eful training (Fridriksson et al., 2005). When collapsing the total number of correctly named items across treatment probes for all participants, Fridriksson et al. (2005) found a statistically significant advantage for RP compared to Eful. In this review, Fridriksson et al. (2005) is the only RP study to have manipulated the *time* elapsed between repeated training trials as opposed to the *number* of subsequent training trials between repeated trials of the same target. Inter-stimulus intervals achieved by manipulating time are amenable to a concurrent second therapy task completed during spacing intervals. Fridriksson et al. (2005) found improved outcomes in naming *and* the concurrent writing treatment.

4. Discussion

This scoping review aimed to apply the RTSS to ELess, Eful, and RP for naming in aphasia to clarify the potential MoAs and central treatment ingredients. Within the discussion, we describe and consider gaps in these areas that were revealed through the scoping review process.

4.4. Mechanisms of Action

Four potential MoAs were identified across the studies and 17 of the 19 studies identified an MoA for at least one of the compared interventions. There is no consensus as to which mechanism(s) of learning likely underlie ELess, Eful, and RP approaches. Interestingly, the results of the reviewed studies were not always consistent with the hypothesized MoAs. These discrepancies may call into question the proposed MoAs or be a result of methodological or statistical limitations.

Most of the reviewed papers aimed to compare the relative effectiveness of interventions rather than evaluate the proposed MoAs. Evaluating MoAs requires theoretically motivated, iterative research (Boyle et al., 2022) and can support designing and modifying treatments in ways faithful to the underlying MoA(s). Schuchard and Middleton (2018a, 2018b) have begun to engage in this process when evaluating incremental learning via lexical access as a mechanism in ELess and RP. This work has implications for the selection of treatment ingredients based on a client's language deficits. Future research can move towards the evaluation of hypothesized MoAs. For example, work can evaluate whether Hebbian learning is gated by cognitive-linguistic skills during naming treatment for aphasia. Gated-Hebbian learning can be supported or disputed by comparing outcomes under low- and high-error training conditions with a large sample of clients with and without cognitive-linguistic impairments in areas hypothesized to augment learning. Findings would establish whether cognitive-linguistic abilities should be considered when selecting ingredients that affect error-rate.

Studies evaluating the MoAs of ELess, Eful, and RP may produce findings suggesting that MoAs co-exist in a single intervention. Figure 3 illustrates which MoAs may operate concurrently during ELess, Eful, or RP. Hebbian learning, for instance, is a basic tenet of neuroplasticity and likely involved when internal representations are modified through repeated practice. Effortful retrieval may apply in any intervention involving retrieval of information from long-term memory while incremental learning via lexical access may warrant consideration when treatments require participants to activate lexical representations. The classification of ELess, Eful, and RP into three distinct treatments with separable MoAs may limit consideration of how ingredients can be applied to align with multiple theoretical frameworks. Note that Figure 3 combines Hebbian and gated-Hebbian learning into one MoA. As described previously, it has yet to be determined whether error correcting mechanisms moderate Hebbian learning, a key area of future research.

[Figure 3 about here]

Finally, the proposed MoAs may not be comprehensive. Implicit and explicit learning mechanisms have been more thoroughly evaluated in fields outside of aphasia. Implicit/explicit learning mechanisms may be relevant given that ELess is hypothesized to rely on implicit memory and thus, be beneficial for those with declarative memory impairments (e.g., amnesia) (Baddeley & Wilson, 1994; cf., Tailby & Haslam, 2003). It remains to be elucidated whether structural impairments to memory systems are associated with distinct learning profiles under ELess, Eful, and/or RP in aphasia. Given that memory is not a primary impairment in aphasia following acquired brain injury, implicit *and* explicit memory has not been probed in aphasia to determine their contribution to success in ELess and Eful contexts. While errors are at the forefront of the ELess and Eful comparison, there is no mechanistic rationale motivating error inflation during naming treatment for aphasia considering the subsequent impacts on relearning. Literature in other

disciplines posits that during novel declarative learning tasks, errors act as future retrieval cues (Pyc & Rawson, 2012) or induce curiosity (Potts et al., 2019). However, it is unclear how these hypothesized mechanisms would relate to the retrieval of abstract, language-based representations (e.g., lemmas, Dell, 1986, or word forms, Caramazza, 1997) or operate within an impaired language system (e.g., error-learning, Middleton & Schwartz, 2013).

4.2. Ingredients

4.2.a. Success and Effort. Success and effort are prominent within the MoAs proposed for ELess and RP learning that are manipulated via treatment ingredients including cues (e.g., Abel et al., 2005) and the spacing of repeated training trials of the same target (e.g., Middleton et al., 2016). Spacing retrieval during therapy is thought to establish conditions in which a memory trace is fading and thus retrieval is effortful while remaining successful. Learning improves when items were spaced compared to massed within and across sessions (Lacey et al., 2004; Middleton et al., 2016, 2019). Despite benefits for spaced over massed learning within single training sessions, the spacing effect may diminish when training occurs over multiple sessions rather than within a single session (Middleton et al., 2019). A reduction in the spacing effect over multiple sessions is likely because both spaced and massed conditions benefit from the lag between training sessions. For language rehabilitation which occurs over multiple sessions, distributed practice principles that take advantage of across-session spacing may be preferred. Recent work suggests that spacing training trials of the same target across sessions is more beneficial than spacing within a session (Schuchard et al., 2020). In that study, seven days after training, naming accuracy was 21% higher for items named at a criterion of two (i.e., named accurately twice per session) across two sessions compared to items named at a criterion of four within one session. Given that effort and success are consistently identified as key aspects of ELess, Eful, and RP, future research can elucidate

how clinicians can take advantage of various treatment ingredients including cues, within or across session spacing, and criterion of learning to achieve the desired level of effort and success for optimal learning.

4.2.b. Feedback. The notion that feedback is an important ingredient for naming interventions aligns with a recent metaanalysis that aimed to determine key components associated with successful naming interventions. Sze et al. (2021) found that feedback on the accuracy of a naming response was one of the most important factors for improved naming performance. From the perspective of proposed MoAs, Eful has been modeled as being gated by cognitive-linguistic skills including error detection (Lambon Ralph & Fillingham, 2007). Detection of errant behavior describes the recognition that an action conflicts with what is believed to be true and is considered a precursor for updating erroneous memory traces. Broadly, error detection is described as being either internally driven via self-monitoring or externally driven via the provision of feedback (Ohlsson, 1996; Postma, 2000). Self-monitoring abilities of naming may vary among people with aphasia (e.g., Schwartz et al., 2016) and depend on item difficulty, aphasia severity, and aphasia type (Nozari et al., 2011; Sampson & Faroqi-Shah, 2011). Fillingham et al. (2005a, 2005b, 2006) reported significant correlations between accuracy judgments on a naming test and ELess and Eful outcomes. However, the ability to detect feedback and use feedback to modify future performance has not been evaluated in aphasia, to our knowledge. External error monitoring via feedback may be particularly relevant when a person with aphasia is unable to self-monitor the accuracy of their responses.

Feedback was found to vary in its informativeness. In psychology and education research, the provision of informative feedback has been found to lead to greater learning gains and long-term retention relative to corrective feedback (Bangert-Drowns et al., 1991; Gilman, 1969; Pashler

et al., 2005). However, no study within this review evaluated how the *information* conveyed by feedback influenced learning via systematic evaluation. Furthermore, only one study (McKissock et al., 2007) systematically compared Eful interventions with and without feedback within the same study. Further exploration of feedback may reveal whether feedback is an active ingredient within ELess, Eful, and RP interventions for aphasia, what information feedback should contain, and which individuals may benefit from feedback.

Eight studies discussed the influence of Eful (often associated with negative feedback) on motivation, effort, and treatment preference (Abel et al., 2005; Choe et al., 2017; Conroy et al., 2009a, 2009b; Fillingham et al., 2005b, 2006; Lacey, 2010; McKissock & Ward, 2007). The consequences of negative feedback on motivation and effort have not been systematically evaluated in the context of ELess, Eful, and RP using quantitative or qualitative methods. Client motivation is a relevant factor to consider and has been found to influence learning in education and psychology (Bourgeois et al., 2016; Pintrich, 2003).

4.2.c. Linking Ingredients to MoAs

Currently, treatment ingredients are mapped onto specific treatment approaches (e.g., repetition-based approaches are classified as ELess). This classification likely stems from initial research studies which aimed to determine whether error-rate (ELess, Eful) and/or participant effort (ELess, RP) influenced learning. However, as the mechanistic underpinnings of these approaches as they related to naming in aphasia continue to develop, a more useful conceptualization may be linking treatment ingredients to proposed MoAs as is illustrated in Figure 4. Within this framework, clinicians are not bound by a specific treatment approach and can precisely apply treatment ingredients that engage desired MoAs.

4.3. Individual Impairment Profile

Eight studies considered the contribution of cognitive-linguistic skills to outcomes under ELess and EFul naming conditions with inconsistent findings, potentially calling into question gated-Hebbian learning as an MoA (Choe et al., 2017; Conroy et al., 2009a, 2009b; Fillingham et al., 2005a, 2005b, 2006; Lacey, 2010; McKissock & Ward, 2007). Measures of cognition are known to map onto multiple cognitive constructs. Skills such as executive functioning may be more effective to evaluate with latent variable approaches (e.g., Miyake et al., 2000) and may provide additional insight into the role of specific cognitive constructs in EFul. Small sample sizes and differences in study ingredients may also contribute to inconsistent results highlighting the need for ongoing work. Lambon Ralph et al. (2010) combined data from four increasing cue studies and found that measures of attention, but not executive functioning were associated with therapy gain immediately post-treatment and at follow-up. Interestingly, the lack of a relationship between executive skills and treatment response in Lambon Ralph et al. (2010) is inconsistent with at least one of its constituent studies (Fillingham et al., 2006) potentially due to the methodological and/or statistical irregularities across the amalgamated studies. Cognitive skills such as working memory and attention may be relevant for RP in aphasia if these skills mediate retrieval difficulty but have not been evaluated (see Brewer & Unsworth, 2012; Dudukovic et al., 2009; Maddox et al., 2011; Maddox & Balota, 2015). If cognition is a key factor for ELess, EFul, or RP, future research can evaluate how to support cognition at the individual level.

Research comparing ELess and EFul has not consistently found a relationship between language impairment profile and treatment outcomes when evaluated (Fillingham et al., 2005a, 2005b, 2006). This may be because the mechanism underlying ELess and EFul are independent of language. Alternatively, it could mean that selected language measures are not sensitive to the kinds of impairments that interact with treatment type. Schuchard and colleagues (2018a, 2018b)

have done work that suggests that RP and ELess may be more effective at treating naming impairments at the level of semantics or phonology, respectively. However, conclusions from this work are preliminary and may benefit from additional large-scale studies. The severity of naming impairment may also interact with treatment outcomes and may be further evaluated. Middleton et al. (2015) found that the benefits of RP are most strongly associated with trials in which retrieval is successful. Future research may evaluate whether individuals who make more errors respond differently to approaches or ingredients that promote successful retrieval.

4.4. Further Considerations

When evaluating treatment methods, it is important to consider the relative difficulty of implementing them within the standard clinical practice. Seven studies remarked on the challenges of managing cue hierarchies or spaced retrieval intervals (Conroy et al., 2009a, 2009b; Fillingham et al., 2005a, 2005b, 2006; Fridriksson et al., 2005; McKissock & Ward, 2007). Implementation of evidence-based practices in the clinical environment is enhanced when approaches reduce barriers including those imposed by time, treatment complexity, and environmental constraints (Fucetola et al., 2005; Olswang & Prelock, 2015; Shrubsole et al., 2019). Given that treatment complexity has been identified as a potential barrier within some studies, it is important to engage stakeholders in subsequent studies and determine how to reduce complexity while maintaining faithful to key treatment ingredients.

Recently, the field of speech-language pathology is recognizing the importance of describing studies within a unified framework to improve treatment fidelity, allow clinicians to modify treatments based on individual impairment profiles, and help researchers address gaps in the literature (Basilakos et al., 2022; Boyle et al., 2022; Cherney et al., 2022; Fridriksson et al., 2022; Van Stan et al., 2021). The current scoping review demonstrates that it is feasible to apply

the RTSS retrospectively to ELess, Eful, and RP and that it can be useful in clarifying related interventions. In ELess, Eful, and RP research, the RTSS may aid researchers in identifying whether ELess, Eful, and RP are distinct enough to be considered unique treatments. In a consensus study seeking to identify ingredients and MoAs in voice treatments, Van Stan et al. (2021) noted that equivalent outcomes in comparative effectiveness studies could be the result of comparing studies that consist of primarily the same active ingredients. It is possible that ELess, Eful, and RP share the same primary ingredient (e.g., opportunities to produce names for targets) with other ingredients being volitional in nature (e.g., targeting motivation or performance, see Whyte et al., 2019). However, because RP has shown advantages relative to ELess and Eful, RP is more likely to contain distinguishing ingredients.

While the RTSS supported the systematic evaluation of ingredients and MoAs in ELess, Eful, and RP, there were challenges in applying this framework to language rehabilitation. Within the RTSS, a distinction is made between ingredients that target a treatment group vs. client volition (e.g., motivation, effort, performance accuracy) (Whyte et al., 2019). Treatment ingredients addressing effort or success are characterized in the RTSS as volitional while in ELess, Eful, and RP for naming in aphasia, these ingredients are hypothesized to play a key role in altering internal language representations and ultimately, the skill and habit of naming. Constructs of effort and success may play a distinct role when the target of treatment is an abstract mental representation. Additionally, the current review highlights the importance of (1) a precisely defined MoA (e.g., learning by practicing mapping from the word form to phonology) and (2) a means to capture multiple MoAs for a single target. Describing these findings using the RTSS is challenging given that the RTSS defines the MoA for treatments targeting skills and habits as “learning by doing” and provides guidance on applying one MoA to one target. Ongoing consideration of the

application of the RTSS to language rehabilitation will further strengthen clinicians' and researchers' ability to uphold theory-driven language treatment.

4.5. Limitations

Given the variability of terms used to refer to interventions that manipulate success and error rate during naming treatment for aphasia, it is possible that some papers were not identified in the current review. Additionally, the reviewed studies were not written using the RTSS framework. Thus, MoAs and ingredients had to be extrapolated based on information provided by the original authors which may not include aspects of treatment that the authors deemed evident.

5. Conclusion

Applying the RTSS to a systematic scoping review of ELess, Eful, and RP provides initial insights into hypothesized MoAs and ingredients that may produce change in naming. Gaps identified can drive future research that aims to (1) conduct iterative studies that aim to support or dispute MoAs through theory-driven comparative effectiveness research, (2) determine which ingredients are likely active and their relation to proposed MoAs, and (3) identify how individual-level factors can guide treatment selection and modification within the proposed theoretical frameworks. Ongoing efforts to determine the learning mechanisms responsible for creating durable change within the language system and ingredients that support these mechanisms may reduce variability in treatment response by enhancing a clinician's ability to administer treatments in accordance with the underlying MoA(s).

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Table 1.

Treatment ingredients and outcomes across studies comparing ELess, Eful, and RP for naming in aphasia.

Figure 1.

Schematic illustrating ELess, Eful, and RP for naming in aphasia.

Figure 2.

PRISMA diagram showing sources of evidence, studies screened, studies retrieved for full-text review, and studies included.

Figure 3.

An illustration of which MoAs may operate concurrently during a single intervention. Dividing ELess, EFul, and RP into three separable interventions may limit consideration of how MoAs co-exist within a learning context.

Figure 4.

Active ingredients as they may map onto proposed MoAs. Under each MoA, a broad active ingredient is listed and describes the types of naming opportunities that are hypothesized to confer change under each MoA. Underneath the broad active ingredients are ways in which these types of productions have been elicited in the reviewed literature and are tools that clinicians may be able to utilize to engage a desired MoA.

Learning Objectives:

1. Describe the mechanisms of actions proposed to underlie ELess, EFul, and RP for naming in aphasia.
2. Contrast ingredients used in ELess, EFul, and RP in aphasia.
3. Explain how variations in treatment ingredients may influence learning and how this may differ based on an individual's cognitive or language impairment profile.

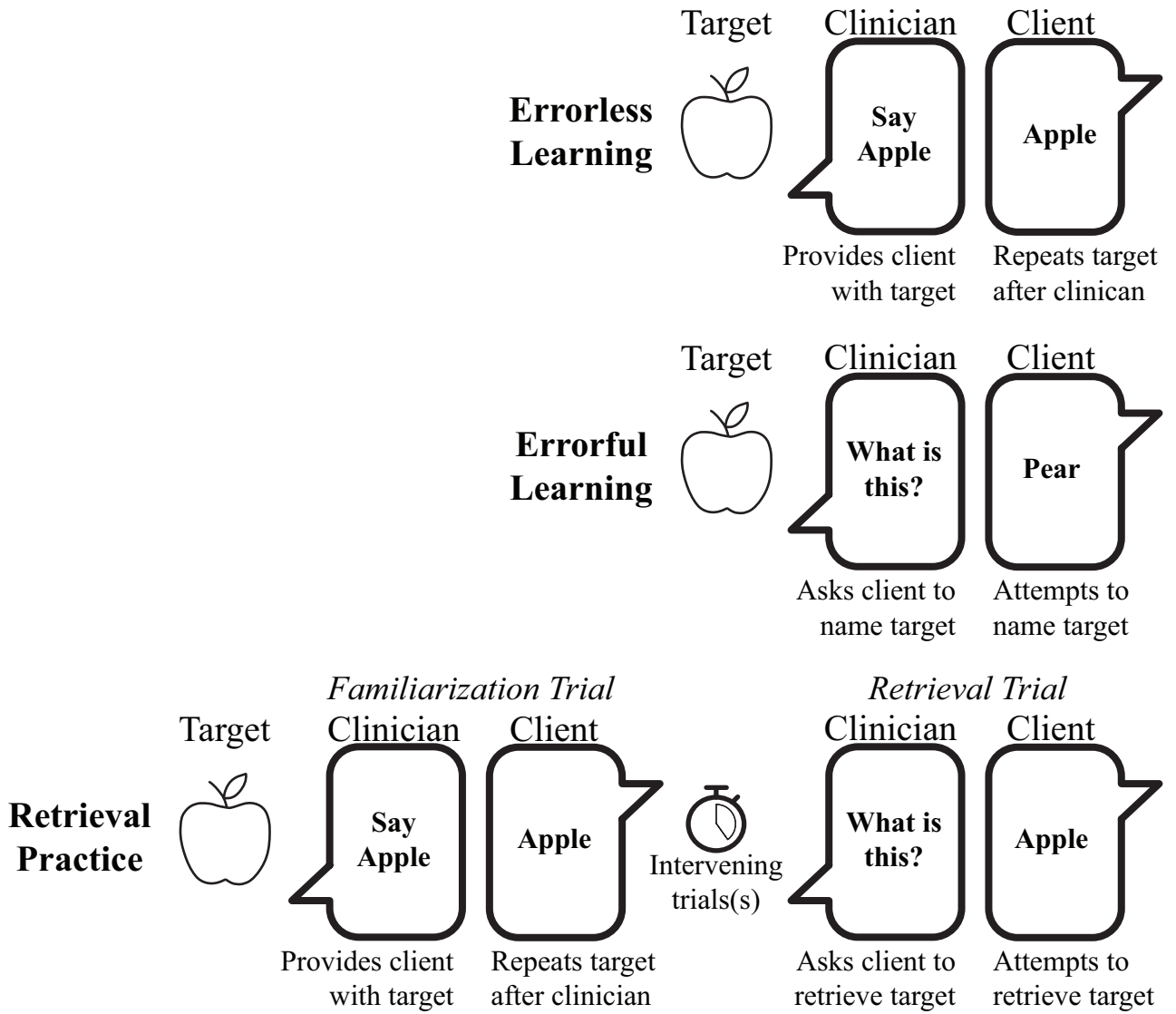


Figure 2. PRISMA diagram showing sources of evidence, studies screened, studies retrieved for full-text review, and studies

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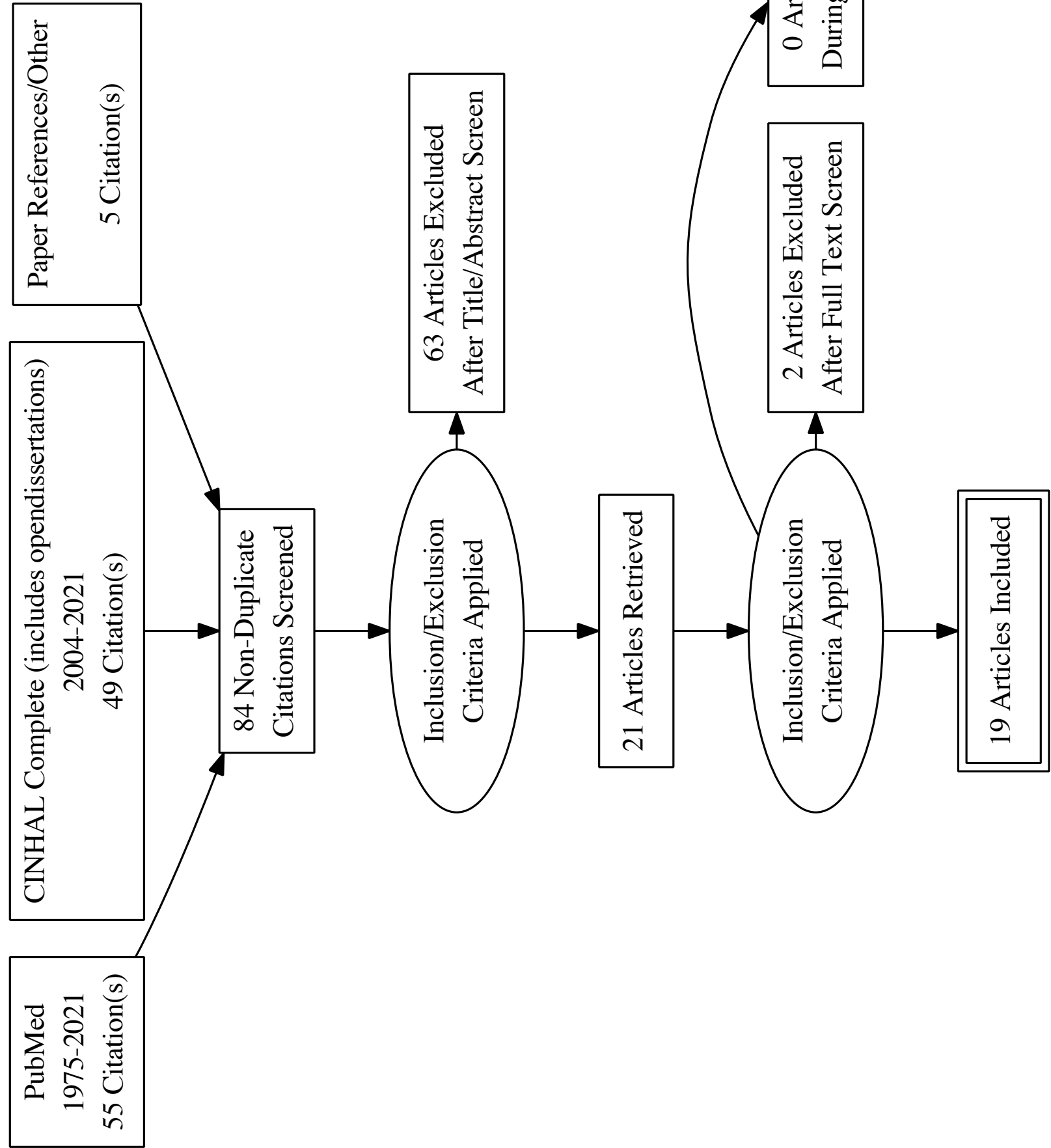


Figure 3. An illustration of which MoAs may operate concurrently during a single intervention. Dividing ELess, Eful, and RP into three separable interventions may limit

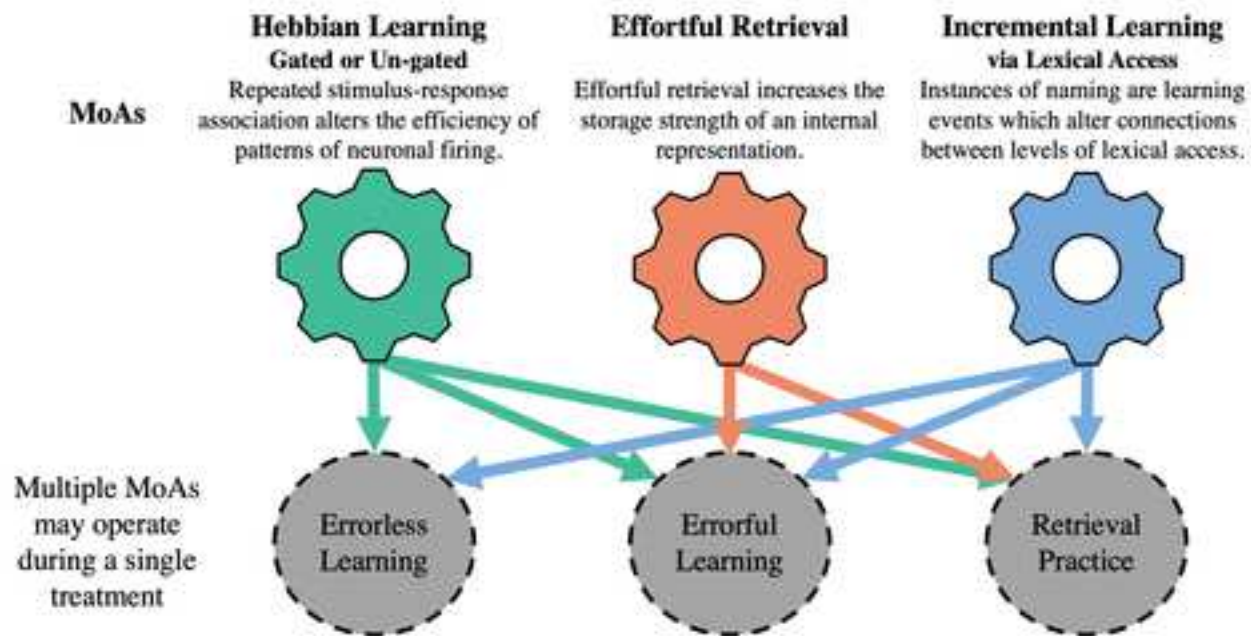


Figure 4. Active ingredients as they may map onto proposed MoAs. Under each MoA, a broad active ingredient is listed and describes the types of naming opportunities that

Hebbian Learning	Gated Hebbian Learning	Effortful Retrieval	Incremental Learning via Lexical Access
<p><u>Opportunities to practice successful naming</u></p> <ul style="list-style-type: none">• Whole word repetition• Cues that reduce errors (e.g., decreasing cues)• Massed practice	<p><u>Opportunities to practice naming</u></p> <ul style="list-style-type: none">• Informative feedback	<p><u>Opportunities to practice effortful yet successful naming</u></p> <ul style="list-style-type: none">• Cues that prioritize effort while maximizing success (e.g., cued retrieval)• Spaced practice• Informative feedback	<p><u>Opportunities to practice Stage 1 and/or Stage 2 of lexical access</u></p> <ul style="list-style-type: none">• Repetition (Stage 1)• Retrieval practice (e.g., spaced retrieval) (Stage 1 and 2)

Table 1

Treatment ingredients and outcomes across studies comparing errorless learning, errorful learning, and retrieval practice for naming in aphasia.

Study	Experimental Design					Outcome			
	Comparison	N	Cues	Feedback	Intensity and Design	Analysis Level	Timing	Results	Statistics
Lacey et al., 2004	ELess v. EFul	1	<u>Study 1 & 2[†]</u> : ELess: Decreasing cues, within trial	<u>Study 1:</u> ELess: Corrective (I) Informative (-)	<u>Study 1:</u> - Design NS - 20 items - Trained over 35 (EFul) and 40 (ELess) sessions	<u>Study 1:</u> SC SC	Tx 1 m	ELess < EFul ELess < EFul	None None
			EFul: Increasing cues, within trial, [†] <i>Study 2 included a spaced retrieval manipulation</i>	EFul: Corrective (I)	<u>Study 2:</u> - Naming attempts NS	<u>Study 2:</u> SC	Tx	ELess = EFul <i>%acc-tx</i>	None
Abel et al., 2005	ELess v. EFul <i>Combined ELess & EFul condition not included</i>	10	ELess: Decreasing cues, within trial EFul: Increasing cues, within trial	Corrective (I)	- Alternating tx - 25 items (10 items trained/session) - Trained 5x/wk for 4wks - Each item trained in two sessions - 5 trials/ session - Naming attempts based on accuracy	G MC	Same day Same day	ELess < EFul ELess = EFul <i>Diff score: same-day post-test minus pre-tx baseline.</i>	Mann-Whitney U-test* Fisher test*

Study	Experimental Design						Outcome		
	Comparison	N	Cues	Feedback	Intensity and Design	Analysis Level	Timing	Results	Statistics
Fillingham et al., 2005a	ELess v. EFul	7	ELess: Spoken and written word EFul: Word initial phoneme and grapheme	None	- Parallel tx design	MC	1 wk	ELess = EFul	NS
					- 20 items	MC	5 wks	ELess = EFul	NS
					- Trained 2x/wk for 5 wks			#acc-tx	
					- 9 naming attempts/session				
Fillingham et al., 2005b	ELess v. EFul	7	ELess: Spoken and written word EFul: Word initial phoneme and grapheme	None	- Parallel tx design	MC	1 wk	ELess = EFul	NS
					- 20 items	MC	5 wks	ELess = EFul	NS
					- Trained 2x/wk for 5 wks			#acc-tx	
					- 3 naming attempts/session				
Fridriksson et al., 2005	<i>RP v. EFul</i>	3	RP: None EFul: Increasing cues, within trial	RP: Informative (-) EFul: Corrective (I)	- Sequential - 15 items (3 items trained/session) - Trained 2x/wk for 4-7 wks - 1x/trial, number of trials/session NS	G	Collapsed post-tx probes (2, 6, and 12 wks)	RP > RF #acc-tx	Chi squared
Fillingham et al., 2006	ELess v. EFul	11	ELess: Spoken and written word EFul: Increasing cues, within trial	ELess: None EFul: Corrective (I)	- Sequential tx	MC	1 wk	10/11 ELess = EFul	Chi squared*
					- 30 items	MC	5 wks	1/11 ELess < EFul	Chi squared*
					- Trained 2x/wk for 5wks			9/11 ELess = EFul	
					- ELess: 9 naming attempts/session			2/11 ELess < EFul	
					- EFul: Naming attempts based on accuracy			#acc-tx	

Study	Experimental Design						Outcome		
	Comparison	N	Cues	Feedback	Intensity and Design	Analysis Level	Timing	Results	Statistics
Abel et al., 2007	ELess v. EFul <i>EFul only conditions with semantic v. phonological cues not included</i>	4	ELess: Decreasing cues, within trial. Cue direction reversed if not correct. EFul: Increasing cues, within trial	Corrective (I)	- Alternating tx - 30 items (6 trained/session) - Trained 5x/wk for 2wks - 6 trials/item, each item seen in 2 sessions - Naming attempts based on accuracy	MC	4-6 days	ELess = EFul <i>Diff score: #acc-tx at post-test minus #acc-tx in first 2 sessions.</i>	Exact sign test, one-tailed
McKissock et al., 2007	ELess v. EFul <i>Additional manipulation: feedback</i>	5	ELess: Spoken word EFul-nofb**: None EFul-fb**: None	ELess: NS EFul-nofb: None EFul-fb: Corrective (E) Informative (+/-)	- Parallel tx - 30 items - Trained 1x/wk for 8wks - 1 naming attempt/session	G G MC MC	2 wks 12-14 wks 2 wks 2 wks	ELess > EFul-fb > EFul-nofb = untreated ELess = EFul-fb > EFul-nofb = untreated ELess = EFul-fb 4/5 EFul-fb > EFul-nofb 1/5 EFul-fb = EFul-nofb <i>#acc-un&tx</i>	ANOVA with post-hoc analysis ANOVA with post-hoc analysis Chi squared* Chi squared*

Study	Experimental Design						Outcome			
	Comparison	N	Cues	Feedback	Intensity and Design	Analysis Level	Timing	Results	Statistics	
Conroy et al., 2009a	ELess v. Eful	7	ELess: Decreasing cues, across sessions	ELess: Corrective (I)	- Parallel tx - 40 items - Trained 2x/wk for 5wks	G	Post tx	ELess = Eful	ANOVA	
			Eful: Increasing cues, within trial	Eful: Corrective (I)		MC	1 wk	ELess = Eful	NS*	
						MC	5 wks	ELess = Eful	NS*	
								#acc-tx		
Conroy et al., 2009b	ELess v. Eful	9	ELess: Spoken and written word	ELess: Corrective (E) Informative (-)	- parallel tx - 40 items - Trained 2x/wk for 5wks	G	Post-tx	ELess > Eful (<i>p</i> = .06)	ANOVA	
			Eful**: Increasing cues, within trial	Eful: Corrective (I)		MC	1 wk	8/9 ELess = Eful	Chi-squared*	
						MC	5 wks	1/9 ELess > Eful	Chi-squared*	
								ELess = Eful		
								#acc-tx		
Lacey, 2010	ELess v. Eful	7	ELess: Decreasing cues, within trial	ELess: Corrective (I) Informative (-)	- Parallel tx - 20 items - Trained 2x/wk until criterion or plateau reached	MC	Post-tx	6/7 ELess = Eful	Chi-squared	
	<i>Additional manipulation: spacing of trials</i>		Eful: Increasing cues, within trial	Eful: Corrective (I)		- Naming attempts based on accuracy			1/7 = Eful > ELess	
									#acc-tx	
Thomas et al., 2012	ELess v. Eful	1	ELess: Decreasing cues, within trial	ELess: NS Eful: Corrective (I)	- Alternating tx - 40 items - 1-2x/wk for 3wks					
			Eful: Increasing cues, within trial		- 14 for ELess and accuracy dependent for Eful					
									<i>Excluded from comparative effectiveness section as more errors were produced during ELess relative to Eful training.</i>	

Study	Experimental Design						Outcome		
	Comparison	N	Cues	Feedback	Intensity and Design	Analysis Level	Timing	Results	Statistics
Middleton et al., 2015	ELess v. RP	8	ELess: Spoken and written word	Informative (-/+) <i>After 8s trial</i>	- Sequential tx - 54-116 items - Each item trained in 1 session	G	Same day	ELess = cued RP = uncued RP	Reg
	<i>Additional manipulation: cueing (RP)</i>		RP: <u>Cued trials:</u> Word-onset (spoken and written)		- 2 naming attempts/session (1 fam, 1 tx)	G	1 day	ELess < cued RP; ELess < uncued RP	Reg
			<u>Uncued trials:</u> None			G	1 wk	ELess < cued RP; ELess = uncued RP	Reg
Middleton et al., 2016	ELess v. RP	4	ELess: Spoken and written word	Informative (-/+) <i>After 8s trial</i>	- 3-4 sequential tx cycles - 180-288 items (trained in sets of 60-72/cycle)	G	1 day	ELess < RP	Reg
	<i>Additional manipulation: within session spacing during a single session</i>		RP: None		- Each item trained in 1 session - 4 naming attempts/session (1 fam, 3 tx)	G	1 wk	ELess < RP <i>%acc-tx</i>	Reg

Study	Experimental Design					Outcome			
	Comparison	N	Cues	Feedback	Intensity and Design	Analysis Level	Timing	Results	Statistics
Choe et al., 2017	ELess v. EFull	2	ELess: Decreasing, within trial	None	- Sequential tx - 12 items	SC (P1)	3-5 wks	ELess = EFull	Friedman
	<i>Independent home-computerized practice</i>		EFull: Increasing, within trial		- P1: Trained avg 5x/wk for 5 wks - P2: Trained avg 7x/wk for 7 wks - ELess: 7 naming attempts/session - EFull: 6 naming attempts/session	SC (P2)	5-7wks	ELess = EFull <i>16pt naming scale score-tx</i>	Friedman
Friedman et al., 2017	ELess v. RP	3	ELess: Spoken and written target to read or repeat	ELess: None	- Parallel tx - 18-22 items - Trained 2x/wk for 3-4 m	G	1 m	ELess < RP	Chi-squared
	<i>Additional manipulation: over-learning (advanced to ELess/RP after test-study phase)</i>		RP: None	RP: Informative (-/+)	- 2-3 naming attempts/session	G	4m	ELess < RP <i>%acc-tx</i>	Chi-squared
	<i>Combined ELess & RP condition not included</i>								
Schuchard & Middleton, 2018a	ELess v. RP	10	ELess: Spoken and written word	Informative (-/+) <i>After 8s trial</i>	- Parallel tx - 44 items - Each item trained in 1 session - 3 naming attempts/session (1 fam, 2 tx)	G	Post-tx	Stage 1 Items: ELess < RP Stage 2 Items: ELess > RP <i>%acc-tx</i>	Reg

Study	Experimental Design						Outcome		
	Comparison	N	Cues	Feedback	Intensity and Design	Analysis Level	Timing	Results	Statistics
Schuchard & Middleton, 2018b	ELess v. RP	2	ELess: Spoken and written word RP: None	Informative (-/+) <i>After 8s trial</i>	- 3 cycles of parallel tx - 108 items (trained in sets of 36) - Each item in 1 session - 4 naming attempts/session (1 fam, 3 tx)	G [†]	1 day	Treatment by pt interaction P1: ELess < RP P2: ELess = RP	Reg
	<i>Additional manipulation: stage of impaired lexical access at the participant level</i>					G [†]	1 wk	RP	Reg
						MC	1 wk	ELess < RP	Reg
					†1 pt per group		ELess = RP		
								%acc-tx	
Middleton et al., 2019	ELess v. RP	4	ELess: Spoken and written word RP: None	Informative (-/+) <i>After 8s trial</i>	- 2 cycles of interleaved tx - 96 items (trained in sets of 48) - Trained 2x/wk for 2wks - 3 naming attempts/session (Session 1: 1 fam, 3 tx Session 2-4: 3 tx)	MC	1 wk	3/4 ELess < RP 1/4 ELess = RP	Reg
	<i>Additional manipulation: within session spacing during multi-session training</i>					G	1 m	ELess < RP	Reg
								%acc-tx	

Note. Abbreviations: ELess: Errorless Learning. Eful: Errorful Learning. RP: Retrieval Practice. (I): Implied Feedback. (E): Explicit feedback. (-): Informative feedback on incorrect trials only. (-/+): Informative feedback on correct and incorrect trials. NS: Not stated. Fam: Familiarization. Tx: Training. Pt: Participant. SC: Single case. MC: Multiple cases. G: Group. #acc-tx: Number of trained items named accurately. #acc-un/tx: Number of trained or untrained items named accurately. %acc-tx: Percent or proportion of trained items named accurately. Diff score: Difference between pre and post-treatment assessment. Reg: Regression Models.

* Did not correct for multiple comparisons

** Aimed to increase errors via guessing