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Bethany G. Gorter
University of Montana, Missoula

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MAKE NO MISTAKE:
THE BENEFITS OF AN ERRORLESS LEARNING PROCEDURE IN A DEPRESSED POPULATION

By

BETHANY G GORTER

Bachelor of Arts, Calvin University, Grand Rapids, MI, 2016

Master of Arts in Clinical Psychology, University of Montana, Missoula, MT, 2019

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Approved by:

Scott Whittenburg, Dean of The Graduate School

Stuart Hall, PhD., Chair
Psychology

Allen Szalda-Petree, PhD
Psychology

Dr. Greg Machek, PhD
Psychology

Dr. Jacqueline Brown, PhD
Psychology

Dr. Erin Semmens, PhD
Public Health

Abstract

Despite evidence of verbal memory deficits in people with depression (Goodall et al., 2018), there are currently minimal studies examining the effectiveness of cognitive rehabilitation techniques in this population, and no studies examining the effectiveness of errorless learning procedures (EL). Errorless learning eliminates errors during encoding which contrasts with traditional trial-and-error, effortful learning (EF). This paper argues that because the memory deficits in depression are largely due to dysexecutive functioning (Snyder 2013) errorless learning procedures could be beneficial to this population because it helps reduce the burden on executive functioning during encoding and retrieval. Moreover, a newer modification of errorless learning that includes semantically rich cues (i.e., errorless learning plus self-generation EL-SG) was included in this study and hypothesized to produce even greater mnemonic benefit by facilitating deeper elaboration on material. This mixed-design study used a stem-completion task in an MTurk sample of 165 participants (60 non-depressed; 65 depressed) to test proposed hypotheses. Analyses revealed that regardless of depression status, participants performed better on immediate free recall following EL learning, which was consistent with proposed hypotheses. Moreover, as anticipated, EL-SG provided an additive advantage over both EL and EF procedures for immediate and cued recall. A novel finding was that participants preferred self-generation procedures far more than the other two learning conditions, which has not yet been examined as a potential mechanism for the errorless learning advantage. In contrast, proposed interaction effects between depression status and learning condition were not observed as there were no memory differences between the depressed and non-depressed group. Additionally, delayed recall performances were not consistent with a priori hypotheses, which may have been due to unanticipated recency effects. Clinical implications and future directions are discussed.

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Make no mistake:

The benefits of an errorless learning procedure in a depressed population

Depression is a highly prevalent and chronic mental illness (16% prevalent rate) with functional impairments that contributes to significant disability and social cost (Kessler et al., 2003; World Health Organization, 2011). Although mood symptoms (e.g., low mood, apathy, hopelessness) are the hallmarks of depression, many researchers assert that psychosocial and functional impairments in depression are caused and maintained by neurocognitive impairments (Cha et al., 2017; Woo et al., 2016; McIntyre et al., 2015). The cognitive deficits associated with depression are wide-ranging, and include deficits in processing speed, attention, working memory, verbal and visual episodic memory, and executive functioning (see East-Richard et al., 2019; Goodall et al., 2018 and Snyder, 2013 for meta-analyses). To reflect the common experience of neurocognitive impairment in major depressive disorder (MDD) the DSM-V includes “diminished ability to think or concentrate” as one of 9 possible symptoms to meet criteria (American Psychiatric Association, 2013).

Although numerous cognitive difficulties have been associated with depression, verbal memory impairment is one of the most commonly reported and chronic deficits observed in depressed populations (e.g., Goodall et al., 2018; Vicent-gil et al., 2018; East-Richard et al., 2019; Bora et al., 2017). Verbal memory is a complex process that involves encoding and retrieving information from short and long-term memory. Verbal memory plays a crucial role in everyday life and functioning, such as successfully remembering conversations, and accomplishing responsibilities at home, school and work. Thus, verbal memory deficits can have serious consequences for functional abilities. Indeed, verbal memory abilities are among the best predictors for psychosocial impairment in depression (Vincent-Gil et al., 2018; Jaeger et al., 2006; Woo et al., 2016).

Several theories have been developed to account for the cognitive deficits associated with depression. One prominent, long-standing theory suggests that cognitive deficits are secondary to low motivational capacity associated with apathy (e.g., Richards & Ruff, 1989). However, more recently, research indicates that cognitive deficits are not solely a consequence of reduced motivation, low mood, or depression severity. Instead, impaired executive functions are argued to underlie depressive symptomology more broadly, including both mood symptoms (e.g., apathy, depressed mood, rumination) and cognitive deficits, such as verbal memory impairment (Levin et al., 2007; Nitschke & Mackiewicz, 2005; Hertel, 2000; Heller & Nitscke, 1997). Findings that indicate cognitive deficits persist long after the classic motivational and mood symptoms have subsided lend support for this idea (e.g., Austin et al., 2001; Jaeger et al., 2006; Woo et al., 2016; Conradi et al., 2011).

The cognitive deficits most commonly linked with depression, including verbal memory deficits, implicate executive functioning abilities. Executive functioning has been defined in many ways, with most agreeing that executive functions represent higher-order cognitive processes in which effortful control is exerted over a situation (e.g., via response inhibition, updating, set-shifting, selection, organization, monitoring, planning, initiation) (Moscovitch, 1992; Miyake et al., 2000; Friedman et al., 2006; Miller & Cohen 2001). For instance, selection refers to attending to aspects of information that is relevant for a goal, while response inhibition refers to suppressing distractors or habitual responses. These mechanisms work together to organize or retrieve information. For instance, when attempting to learn names of new coworkers, selection helps identify unique attributes of each individual, while inhibition suppresses irrelevant information that may interfere with the strength of this organizational strategy.

Executive functioning is critical for learning and memory, as executive functioning allows for the identification of relevant information and the inhibition (i.e., exclusion) of irrelevant information. In fact, research suggests that verbal memory impairments in depression are largely due to executive functioning failures, such as failing to organize information in a way that facilitates storage and retrieval of memory traces, failing to inhibit irrelevant material, and to identify and correct errors (Levin et al., 2007; Snyder et al., 2013), and to spontaneously identify and adopt strategies to support learning and recall (Hertel, 2000).

The nature of verbal memory deficits in depression has been studied with the goal of developing unique treatments to address depressive symptomology. Currently, well-established therapeutic techniques for depression fail to overcome the “65% barrier” of treatment responsiveness (Seligman, 2012), meaning that the success rate of current approaches does not exceed 65%, leaving a considerable portion of depressed people with persistent symptomology. This has prompted research into factors that may limit the effectiveness of front-line approaches. Emerging evidence suggests that neurocognitive deficits is one factor that influences resistance to traditional treatment approaches in depressed populations, such as psychopharmacotherapy (Martinez-aran et al., 2009). Additionally, depressed people with verbal memory deficits tend to respond poorly to commonly used psychotherapies such as cognitive behavioral therapy (CBT) (Kundermann et al., 2015). This may occur because skills learned in therapy are not recalled in daily life. Together, this research suggests that it may be necessary to treat verbal memory deficits in people with depression, to gain traction with other treatment approaches.

In addition to limiting the impact of empirically supported interventions, verbal memory deficits in depression can result in the kinds of daily life experiences that contribute to the emergence of mood symptoms (Airaksinen et al., 2007) and maintain these symptoms over time. Depression has largely been conceptualized as a disorder of inactivity and self-isolation that stems from feeling ineffective in pursuing life goals (Hayes et al., 2012; Beck & Dozios, 2010). Continued avoidance and isolation maintain depressive symptomology by limiting exposure to positive and reinforcing experiences. Verbal memory failures in daily life (e.g., forgetting conversations, difficulty remembering course material) likely perpetuate this cycle by contributing to discouragement, self-isolation and disengagement from meaningful activities. Indeed, verbal memory deficits consistently emerge as one of the best predictors of both perceived and objectively measured psychosocial functioning, occupational success and quality of life in people with depression (Cambridge et al., 2018; McIntyre et al., 2013; Woo et al., 2016). Importantly, these kinds of functional deficits have been shown to exacerbate mood disturbance and depression severity more broadly (McKnight & Kashan, 2009 for review).

Together, this research suggests that specifically targeting neurocognitive failures, including verbal memory deficits, could help to mitigate the impact of cognitive failures on the course of a depressive episode. In fact, there is some evidence that targeting neurocognitive deficits can improve functional abilities in depression. For instance, cognitive retraining and compensatory strategies that optimize existing cognitive abilities have been shown to lead to positive functional outcomes (Elgamal et al., 2007; Vincent-Gil, 2019; Motter et al., 2016, see Baune & Regnar, 2014 for review). However, this research is still in its early stages, and researchers note that common rehabilitation techniques have yet to be explored in depressed populations (McIntyre et al., 2015).

Strategies designed to improve memory and other types of cognitive function have been around for centuries (Wilson & Betteridge, 2019). Most recently, however, the development and use of strategies has focused on the rehabilitation of cognitive function of individuals who have sustained traumatic brain injuries or acquired brain injuries (Wilson et al., 2017). Only very recently, however, have cognitive rehabilitation strategies been applied to mental health concerns, such as depression.

Errorless learning is one strategy that has been shown to improve memory among a variety of populations. Errorless learning is any technique that prevents errors during encoding and encompasses strategies such as the method of vanishing cues (Glisky & Schacter 1987; 1989) and spaced retrieval (Haslam et al., 2011). These strategies are widely used, familiar to cognitive rehabilitation specialists (Wilson et al., 2009) and confer mnemonic benefits even in the context of minimal memory impairments (Hammer et al., 2008; Rodriquez-Fornells et al., 2004; Scheper et al., 2019). Additionally, errorless learning may circumvent impaired executive functioning by eliminating the need to inhibit or monitor for errors during encoding and retrieval (Fillingham et al., 2003; Clare & Jones, 2008). Therefore, errorless learning may be a promising technique to mitigate the negative functional impact of verbal memory deficits for people with depression. This study ultimately seeks to examine the efficacy of errorless learning strategies in a depressed population.

Verbal Memory Deficits in Depression

Episodic memory falls under the broader category of explicit memory, in which information is intentionally, and consciously retrieved (Tulving, 1972). Episodic memory impairments occur for both visual and verbal information during acute phases of depression (Hammer & Ardal, 2009), though research shows that verbal memory deficits are more pronounced than visual deficits, and more persistent (Burt, Niederehe, & Zembar, 1995; Rock et al., 2014; Neu et al., 2001; 2005). Moreover, verbal memory deficits often predate depression symptoms (Airaksinen et al., 2006), and may therefore be a predisposing factor for later developing depression. In fact, some researchers argue that verbal memory deficits may represent a more trait-like state as deficits are observed both before and after the resolution of depressive episodes (Kundermann et al., 2015; Conradi et al., 2011) as well as in people who are at risk for depression due to familial history (Mannie et al., 2009).

Verbal memory deficits in depression show up on a variety of subjective and objective measures. Outside the lab, people with depression frequently report experiencing memory failures (Conradi et al., 2011). Subjective measures provide evidence that people with depression are more likely to experience everyday memory failures, such as forgetting conversations, previously completed activities, changes in routine, or difficulties learning information relevant for managing finances, or completing workplace requirements (Cha et al., 2017; Carrasco et al., 2017; McIntyre et al., 2015)

Inside the lab and in clinical settings, people with depression often demonstrate impairment on visual memory tests in which they are exposed to designs and asked to recall those designs immediately, and after a delay. (Jaeger et al., 2006). Similarly, compared to healthy controls, people with depression show impairments on verbal memory tests that involve brief exposure to verbal material, such as short stories (Beblo et al., 2020) or a list of words (McCall & Dunn, 2003), which are then retrieved immediately and following a delay. Similarly, performance on tests designed for laboratory environments, such as a stem completion task (e.g., ST with 4 possible completions to be learned) also reveal impairment in people with depression when compared to healthy controls (e.g., Jermann et al., 2005).

It is important to note that depression-related memory impairment is noticeable when compared to healthy populations, but the impairment is typically more subtle than that observed in other memory-impaired populations, such as people with traumatic brain injury or dementia (Zakzanis, Leach, Kaplan, 1998). Several factors have been shown to impact the severity of verbal deficits in depression. These include inpatient status, number of previous episodes, co-occurring psychosis or mixed presentation and medication use (Lee et al., 2012, Gorwood et al., 2008; Fossati et al., 2004; Burt et al., 1995). However, other studies suggest heterogeneity, with factors like age, depression severity and subtype, and motivation failing to explain the strength of the relationship between depression and neurocognition (e.g., Austin et al., 2001 for review).

One complicating factor of the more subtle nature of verbal memory deficits in depression is that those deficits may not be detected on tests that are easier in nature, such as cued recall or recognition tests. In contrast, depression related deficits are most evident on effortful memory tasks such as free recall list-learning (Lamar et al., 2010; Fossati et al., 2004; Roa et al., 2016) and longer versus shorter lists of words (Airaksinen, 2006). Likewise, performance on tasks that require strategic organization, such as some list-learning tasks, tend to be more impaired, whereas verbal material that is more easily encoded, such as memory for a story, shows minimal impairment (Lamar et al., 2010).

Executive Functioning as a Mediator for Verbal Learning Deficits in Depression

Consistent with the performance of depressed individuals on memory tasks that require greater executive resources, numerous studies specify the ways in which executive functioning plays a role in verbal memory deficits. For instance, studies show that damage to prefrontal areas following acquired brain injury results in difficulties organizing incoming verbal information in a manner that facilitates stronger memory traces, such as organizing lists of information into meaningful categories or relating information to prior learning and existing semantic networks (see Blumenfeld & Borstein, 2009 for review). Moreover, reductions in executive functioning result in difficulties effectively selecting goal-relevant information from competitors (see Miller & Cohen, 2001, Blumenfeld & Borstein, 2009 for reviews). For example, when distractors, such as similar stimuli or extraneous information, are present during encoding, executive function facilitates selective attention for information that is relevant for the task. In addition, inhibitory control allows for the suppression of irrelevant distractors. Indeed, impaired executive functioning following acquired brain injury often results in difficulty selecting goal-relevant material (Blumenfeld & Borstein, 2009) and inhibiting irrelevant information during memory tasks (Shimamura, 2002) as well as difficulty engaging in appropriate error-monitoring, which includes identifying and correcting errors during memory retrieval and encoding (Metcalf et al., 2007; Anderson, 2003; Levy & Anderson, 2002). Together, this research underscores the complex nature of verbal memory, and highlights the various ways in which executive functions support verbal memory abilities.

Although people with depression have more intact executive functions than those with acquired brain injuries, research suggests that verbal memory impairments in depression are similarly due to poor executive functioning, which is a well-established deficit of depression (Snyder 2013). First, people with depression fail to spontaneously adopt strategic organizational strategies that enhance memory encoding and retrieval. For instance, people with depression demonstrate semantic clustering deficits on list-learning tasks, which mediates verbal memory ability (Elderkin-Thompson et al., 2007) and correlates with depletion in prefrontal executive functioning areas on neuroimaging (Kassel et al., 2016; Roa et al., 2016). Furthermore, failure to spontaneously cluster or group lists of words according to some prominent feature (e.g., category, use, color) is associated with greater memory impairment and more persistent depression (Morimoto et al., 2012). In contrast, depression-related verbal memory deficits are not observed on tasks that minimize the burden on spontaneous organization, such as memory for stories, which provide the reader with greater contextual information that assists encoding and retrieval (Lamar et al., 2010). Importantly, several studies suggest that people with depression have the capacity to organize verbal information for stronger memory traces but fail to do so spontaneously due to limited executive resources. For instance, researchers have shown that when strategies are introduced to facilitate organization of material (Elderkin-Thompson, 2006) or facilitate elaborative encoding by directing attention to the meaningful attributes of information (Hertel, 1994; Hertel, 2000; McFarland et al., 2017) depression-related verbal deficits are eliminated. This suggests that people with depression retain the ability to learn and remember information but fail to do so successfully because of impaired organizational strategies at the initial stages of encoding.

Additionally, people with depression often fail to implement effective retrieval strategies. Numerous studies have revealed that people with depression demonstrate impaired performance on free recall tasks (Fossati et al., 2004; Beblo et al., 2020; Lamar et al., 2010), which requires strategic retrieval and is dependent upon executive function (Moscovitch, 1992). This is contrasted with spared performance on tasks of cued recall, in which cues are provided (e.g., category information) that assist in the retrieval of relevant information (Fossati et al., 2004; Fossati et al., 2002; Roa et al., 2016), thereby obviating the need for executive function. Similarly intact performance is observed on recognition tests, in which participants are presented with information that was previously studied and are asked to simply indicate whether the information was presented previously.

One explanation for these findings is that free recall is facilitated by a “deeper” level of processing during the initial stages of learning which may not occur in depression due to impaired organizational strategies during the initial learning episode. The levels of processing theory (Craik & Lockhart, 1972) asserts that when “deeper” processing occurs at encoding (e.g., connecting information to prior learning, reflection on meaningful attributions) information is more likely to be freely recalled, whereas “shallower” processing relies on additional cues to facilitate memory. Thus, failures to retrieve information using free recall could reflect poor organizational strategies during the initial encoding episode for people with depression. Another explanation is that people with depression fail to self-generate cues or use strategies during retrieval to freely recall information, which requires executive resources and intact source memory (Degl’Innocenti & Backman, 1999). Interestingly, source memory deficits can be overcome by reminding people with depression about the context of the initial learning environment (Hertel & Hardin, 1990). This research suggests that memory storage is intact for people with depression, but that initiating the strategic search for information is impaired.

Finally, it is well-established that people with depression have difficulty monitoring and updating information, and inhibiting irrelevant stimuli in general (e.g., Snyder 2013). These kinds of deficits likely impact the ability of people with depression to monitor memory traces for accuracy and inhibit irrelevant information from encoding and retrieval (Levin et al., 2007). For instance, in a depressed population, Pauls et al., 2015 found that impaired list-learning ability was mediated by poor inhibitory control as indicated by neuropsychological performance. Interestingly, inhibition only mediated free recall performance and not recognition, likely because recognition is a more automatic process that may depend less on the ability to inhibit errors during encoding and retrieval, and do not typically require effortful search attempts.

Similarly, other researchers have observed that increasing task difficultly and the subsequent burden on error-monitoring systems impacts people with depression more than healthy adults (Schroder et al., 2013). This likely occurs because people with depression have depleted error-monitoring abilities more generally, and also because the introduction of errors introduces negative feedback that could elicit negative emotional states that impair performance. In addition to this behavioral evidence, neuroimaging indicates that brain areas associated with effective error-monitoring are typically less active in people with depression (Levin et al., 2007; Heller & Nitscke, 1997 for reviews).

Together, this research suggests that executive functioning is crucial for successful verbal memory, and that depression-related verbal memory deficits are largely accounted for by depleted executive resources. Existing research suggests that depression related verbal memory deficits stem from failures to spontaneously organize and elaborate on verbal information, strategically generate cues (including recalling source memory information) during retrieval, and engage in effective error-monitoring and inhibition during encoding and retrieval. In summary, executive functioning represents the primary target for the development of successful interventions for the verbal memory deficits observed in depression.

History of Errorless Learning

Although memory and executive functioning deficits are commonly observed in depression, they are seldom a target of traditional treatments, and the development and application of strategies aimed at improving cognitive functioning has been accomplished primarily with individuals with acquired and traumatic brain injuries. A pivotal discovery in rehabilitation was the notion that people with severe memory problems should be prohibited from making guesses while learning a task. Terrace (1963) first demonstrated that making errors was not a necessary part of learning. In this experiment, birds were taught to discriminate between the color of two keys. At first, only the target key was illuminated, which prompted the pigeons to make responses that were rewarded. Over many trials, the brightness of the error key was increased, allowing opportunities to make errors, but much later in the learning process compared to typical trial-and-error learning. The other groups of pigeons learned through more traditional trial-and-error reinforcement strategies. Remarkably, Terrace found that pigeons trained under the fading condition made no errors in discriminating the keys, while those in other groups made errors ranging from 31 to 4,153.

Sidman & Stoddard (1967) found similar results in an experiment with intellectually disabled children. Compared to traditional reinforcement learning, fading procedures more effectively taught children to discriminate between circles and ellipses. Similarly, in a series of experiments, Glisky & Schacter (1987; 1989) developed the method of vanishing cues (VC) which involves slowly taking away portions of a stimulus. Using this method, they successfully taught a person with severe amnesia how to use a computer and complete basic job requirements. While these strategies do not entirely *prevent* errors, they are nevertheless error-reducing tactics that could be argued to fall under the umbrella of "errorless learning" (Fillingham et al., 2003).

Based on these previous studies, Baddeley & Wilson (1994) developed a stem-completion list learning task that eliminated errors entirely. A list of words was learned by individuals with amnesia and healthy young and older adults. In the EL condition, participants were told, "I am thinking of a five-letter word beginning with QU and the word is QUOTE, please write that down." In the errorful learning (EF) condition, participants were told, "I am thinking of a five-letter word beginning with QU, can you guess what it might be?" The correct answer was provided after participants produced 4 guesses or after 25 seconds had elapsed. They were then instructed to write it down so that it was more elaborately processed. This procedure was repeated for a total of 9 learning trials. They found that EL techniques benefited every patient with amnesia, including those with dysexecutive problems. Moreover, this technique was more helpful for memory patients than the control groups, although the elderly sample also benefited.

Clinical Applications of Errorless Learning

The benefits of errorless learning have been most studied in the context of non-progressive amnesia secondary to ABI (for example, Lloyd et al., 2009, Page et al., 2006; Squires et al., 1997; Tailby & Haslam, 2003, Cohen et al., 2011). However, it has since been extended to older adults with amnestic mild cognitive impairment (aMCI) (Lubinskiy et al., 2009), Alzheimer's disease (Laffan et al., 2010), children with ABI (Haslam et al., 2017; Haslam, et al., 2012), Korsakoff's syndrome (Kessels, 2007; Komatsu et al., 2000), normal aging (Guild & Anderson, 2012) healthy populations (Heldman et al., 2008), schizophrenia (Pope & Kern, 2009), and OCD (Hammer et al., 2009).

In addition to the numerous populations that have benefitted from EL, studies have demonstrated that EL enhances memory for different kinds of information. The stem completion task developed by Baddeley & Wilson (1994) is the most used paradigm and targets verbal memory through list-learning (Guild & Anderson, 2012; Hammer et al., 2009; Haslam et al., 2012; Heldman et al., 2008; Hunkin et al., 1998; Lubinsky et al., 2009). However, EL procedures have been modified to teach activities of daily living (Cohen et al., 2010), word pair associates (Cyr & Anderson, 2015), names paired with faces (Evans et al., 2000; Hammer et al., 2013; Kessels et al., 2003), route finding (Evans et al., 2000; Jones et al., 2010; Kessels et al., 2007) social science facts (Haslam et al., 2017) and prospective memory (Fish et al., 2015). While errorless learning research is promising, it should be noted that there are some limits to the benefits of errorless learning regarding content. For instance, errorless learning is not as effective as effortful learning when the cues are conceptually related (Cyr & Anderson, 2015; Squires et al., 1997), perhaps because in these cases errors help people elaborate on learning and act as a "bridge" between the cue and the correct answer.

Mechanisms of Errorless Learning

The effectiveness of errorless learning techniques with clinical and non-clinical populations suggests that errorless learning could help address verbal memory failures in depression. There has been a lively debate about potential mechanisms underlying the EL advantage, with researchers arguing that (1) implicit memory (2) residual-episodic memory or (3) executive functioning, could account for the errorless learning advantage. These three mechanisms will be briefly reviewed below, with an in-depth analysis of the third mechanism as this mechanism is most relevant for verbal memory impairment in depression.

Implicit Memory

The theory that implicit memory may underlie the effectiveness of EL was first introduced by Baddeley & Wilson (1994) and has since been supported by several other researchers. The gist of this argument is that people with severe memory impairments typically have spared implicit memory recall, which encodes errors and correct answers in a similar manner. Unfortunately, this sets up competing memory traces that cannot be differentiated during retrieval. Errorless learning capitalizes on existing implicit memory by only revealing the correct content, thereby eliminating unconscious memory traces for errors. Conversely, people with intact explicit memory can consciously recollect errors and correct answers and discriminate between them appropriately at recall. As a result, they argued that errorless learning only benefits people who depend upon implicit memory.

In addition to this seminal argument, subsequent groups defend implicit memory as a primary mechanism of errorless learning benefits (Evans et al., 2000; Fish et al., 2015) and have modified the original paradigm to demonstrate this point (Anderson & Craik, 2006; Page et al., 2006). For instance, Page et al., 2006 administered a stem completion task to people with moderate and severe memory impairments. They included a measure of source memory, which is commonly considered a measure of explicit recall. They observed that both moderate and severely memory-impaired participants benefited from errorless learning, even in the absence of source memory, suggesting that errorless learning does not depend upon explicit recall abilities. Moreover, they compared performance on their measure of implicit recall (stem-completion task) with performance on the commonly used explicit recall task (cued recall). Results showed that errorless learning did not benefit explicit recall any more than implicit recall, which they use as evidence that implicit recall was recruited for both tasks. Together these findings support the role of implicit memory in errorless learning.

In contrast, recent research indicating benefits of EL for healthy adults with intact explicit memory has brought these conclusions into question (Hammer et al., 2009; Rodriquez-Fornells et al., 2004; Scheper et al., 2019).

Explicit Memory

In opposition to the implicit memory viewpoint, a second theory has emerged in which explicit memory is purported to drive the errorless learning advantage (Squires et al., 1997; Hunkin et al., 1998). Squire and colleagues argue that errorless learning reduces the burden on explicit memory by eliminating the need to discriminate between error and target at recall. This viewpoint has been supported by the observation that errorless learning improves explicit memory tasks (i.e., free recall) (Hunkin et al., 1998) and facilities learning for memory impaired individuals who still retain some explicit memory as opposed to those with more severe impairments (Tailby & Haslam, 2003). Others have similarly defended the role of explicit memory in errorless learning (Kessels et al., 2005; Kessels & de Hann, 2003).

Executive Functioning

Other researchers argue that EL eases the burden on executive functioning by circumventing the need to inhibit errors during encoding and retrieval (Fillingham et al., 2003; Clare & Jones, 2008). Indeed, multiple studies have demonstrated EL benefits in populations that do not have severe memory deficits, such as individuals with schizophrenia (Pope & Kern et al., 2006), second-language speakers learning to discriminate sounds (McClandiss et al., 2002) and even healthy adults (Shepner et al., 2019). Thus, it is probable that cognitive mechanisms other than implicit or explicit memory mediate these benefits.

Fillingham et al., (2003) drew on Hebbian learning to demonstrate the role of executive functions in EL vs. EF learning. Hebb's theory (1949) asserts that when a cue and stimulus co-occur, a neural pathway is immediately created. Repeated coactivation of material results in associative learning, which occurs without explicit verbal feedback. However, one of the drawbacks is that errors can become similarly coactivated and learned (Fillingham et al., 2003). Thus, merely being exposed to errors during acquisition results in associative learning for errors, which later competes with the desired association during recall. Indeed, associative learning for errors has been shown in experimental studies using common Hebbian paradigms (Lafond, 2010).

Importantly, research suggests that errors learned via Hebbian learning can be moderated via executive functioning processes such as error-monitoring. In order to study this, McCandliss (2002) contrasted EL vs. EF learning using feedback and no feedback. Japanese participants were taught to discriminate between the English “l” and “r” which is difficult to do in adulthood. The errorless learning condition involved adaptive learning in which exaggerated sounds were gradually faded until the normal sounds could be discriminated. This left some room for errors and feedback. The errorful group used a fixed approach in which the “l” and “r” sounds were presented as normal.

Consistent with accounts of Hebbian learning without feedback, errorless learning resulted in improvements over 3 days, as the correct answer was produced by participants and subsequently reinforced over time. Conversely, without feedback, effortful learning did not result in learning benefits, as the incorrect answer was most commonly produced and reinforced over time. Importantly, once feedback was introduced, both learning conditions benefited. This pattern suggests that it is possible to minimize the impact of errors on learning even after the initial error association has been encoded. The authors theorize that either feedback modulated Hebbian learning, or a form of reinforcement learning occurred. In either case, this study demonstrates that control processes are capable of inhibiting errors initially made during learning, to avoid the continual repetition of the same error or mistake. In terms of the mechanism underlying errorless learning, this study suggests that errorless learning may function to reduce reliance on control processes during retrieval, as there are no competing errors to inhibit.

Neuroimaging studies provide some support that executive functioning is used to monitor and inhibit errors during learning. In a group of healthy adults, Hammer et al., (2011) had participants learn lists of words using either errorless or effortful learning. Participants experienced either sham or real transcranial direct current stimulation (tDCS) of the dorsolateral prefrontal cortex (dPFC) which is believed to be involved in error-monitoring. Importantly, they used cathodal stimulation, by which they inhibited the involvement of the dPFC, thus removing the ability to effectively monitor errors. They observed similar recall performance during errorless learning regardless of whether the dPFC was inhibited, suggesting that errorless learning does not elicit error-monitoring abilities. Moreover, in the errorful learning condition, dPFC inhibition resulted in worse recall as compared to sham stimulation, suggesting that errorful learning depends upon error-monitoring abilities for successful recall.

Overall, the above research underscores the role that error-monitoring and inhibition systems play when errors are introduced during learning. Thus, it is likely that clinical populations with poor error-monitoring systems would struggle under errorful learning but benefit from errorless learning. This theory has been examined in a handful of clinical populations (Pope & Kerns, 2006; Hammer et al., 2009), but has not yet been examined in depressed populations.

Executive functioning in EL paradigms. There are relatively few EL studies that assess executive functioning abilities objectively and separately from memory abilities to elucidate the role of executive functioning in EL (Clare & Jones, 2008). Several case studies have been conducted with people who have both significant executive problems *and* memory impairment. Cohen et al., (2010) implemented a rehabilitation strategy with a woman who had both profound memory and executive functioning impairments on neuropsychological measures. Methods involved a variety of errorless techniques, including the use of cue cards, spaced retrieval, and the general prevention of errors. Over the course of 7 years, she demonstrated remarkable improvements in activities of daily living, increased quality of life, and decreased oppositional behaviors. Similarly, Pitel et al., (2009) conducted two case studies with individuals who had both amnesia and executive impairments, although this occurred over a much shorter time period. Errorless learning resulted in better acquisition of semantic information, which generalized to real-world settings. However, it appeared to be most effective for the individual with less significant executive difficulties. Together, these studies suggest that errorless learning may help to bypass executive problems, although this could manifest differently depending upon factors such as length of treatment or severity of executive deficits.

A handful of experimental studies interpret the benefits of EL within the context of executive functioning. One takeaway from these studies is that the impact of errorless learning may depend upon the nature of the executive impairment present in the group. For instance, two groups of researchers argue that errorless learning primarily helps reduce reliance on error-monitoring (Bertens et al., 2015; Pope & Kern, 2006), while another group argues that it limits the need to rely on inhibitory control during encoding (Guild & Anderson, 2012).

In a randomized control trial, Bertens et al., (2015) taught people with well-defined dysexecutive problems Goal Management Training (GMT), which is a treatment package comprised of compensatory strategies meant to overcome dysexecutive problems in planning, monitoring, and initiating behavior. Patients learned GMT using errorless or effortful learning techniques and then used GMT to accomplish activities of daily living and personal goals. Patients in the EL group demonstrated the greatest improvements in activities of daily living and completed personal goals more often and to a higher standard than the effortful group. The authors reasoned that errorless learning helped dysexecutive patients overcome an ineffective error-monitoring system, by preventing exposure and then subsequent consolidation of errors during the learning phase. In other words, the patients did not have to depend upon impaired executive functioning to identify and correct memory traces for errors.

However, it should be noted that the dysexecutive deficits observed in the group was diverse. For instance, to be identified as possessing executive function deficits, performance on only 2/7 neuropsychological tests needed to be impaired, which included tests from a variety of domains such as updating, shifting, and inhibition. Although these domains likely share a common factor, they are also distinct (Friedman et al., 2008; Miyake et al., 2000). Therefore, it is difficult to conclude whether errorless learning benefited all kinds of executive functioning abilities involved in learning, or if it selectively addressed one domain within executive functioning.

Researchers have argued that deficits in inhibitory control may also benefit from errorless learning. For instance, Guild & Anderson (2012) administered a stem-completion task to elderly adults that included an errorless and errorful condition, with answers that were either self-generated or examiner-generated. Overall, errorless learning was more beneficial than effortful learning, regardless of whether answers were self-, or experimenter generated. However, they observed an interesting trend in which self-generated errors (e.g., independently producing the incorrect answer “goat” to the cue “I am thinking of an animal”) were more detrimental to learning than were experimenter generated errors (e.g., “I am thinking of an animal. It is not a pig, it is not a goat, and it is not a fox”). They argue that the act of generating one’s own error requires greater attention and effort, thus resulting in divided attention during encoding, which weakens the memory trace for the correct answer. Thus, errorless learning may partially benefit elderly populations not just by capitalizing on implicit memory capacities (Baddeley & Wilson, 1994), but also by limiting the attentional and inhibitory burden that occurs during the encoding phase.

Similarly, Pope & Kern (2006) examined the benefits of errorless versus effortful learning in a group of individuals with schizophrenia, who often have impairments in verbal memory which is largely attributed to executive functioning difficulties. Interestingly, patients and controls benefited equally from errorless learning, which is in contrast to studies which shows that errorless learning benefits severely amnesic populations more than healthy controls (Baddeley & Wilson, 1994). Rather, the negative impact of errors was more pronounced in the group with schizophrenia. Although these authors did not objectively measure executive functioning abilities, they argued that the group with schizophrenia was more impaired during effortful learning because of impaired error-monitoring abilities. Thus, similar to Bertens et al., (2015), they argue that errorless learning is primarily advantageous for people with dysexecutive functioning because it reduces the need to depend upon impaired error-monitoring abilities. Together, the above research suggests that errorless learning is beneficial to people with impaired executive functions.

In contrast, others argue that reducing errors is beneficial even for people with healthy executive functioning and error-monitoring abilities. Schepner et al., (2019) created a new paradigm to study EL in which the number of errors generated could be more tightly restricted, with either no errors or 2-5 errors, for a total of four effortful learning conditions. Healthy adults were required to put virtual “items” into file draws, and then recall where they went immediately after the study phase was completed. Healthy adults were more accurate in the errorless condition as compared to the effortful. However, the number of errors committed had no impact on recall. Since the healthy group had intact explicit memory, these authors reasoned that superior performance under the errorless condition was most indicative of an error-monitoring mechanism rather than facilitating the efficiency of memory structures more directly (i.e., implicit, and explicit memory). Similarly, Hammer et al., (2013) also manipulated the number of errors that occurred during encoding in a healthy population. However, unlike Schepner et al., (2019) they found that additional errors resulted in worse recall, which they interpreted as representing a dose response, in which more errors placed a greater burden on error-monitoring. Together, these studies suggest that avoiding errors during learning is beneficial even for those with intact memory, and healthy error-monitoring.

In contrast to the above research, several studies fail to provide evidence that executive functioning is a potential mechanism for errorless learning. For instance, Baddeley & Wilson (1994) observed that errorless learning similarly impacted memory-impaired individuals with and without dysexecutive functioning. Similarly, Anderson et al., (2012) split their older adult group into high or low medial temporal lobe (MTL) ability and high or low frontal lobe (FL) ability. Interestingly, the neuropsychological data revealed little relation between free or cued recall for a stem-completion task. Their only notable observation was that error intrusions were higher in people with low MTL ability, suggesting that errors are more harmful for people with memory impairments, rather than executive impairments. However, the magnitude of this observation was rather small. The authors concluded that the overlap between memory and executive abilities may have impacted results.

A newer modification of errorless learning known as errorless learning with self-generation uses semantically rich cues to elicit the correct answer without errors, which may be particularly beneficial for people with depression because it promotes strategic elaboration of material during encoding. In the original self-generation paradigm, Tailby & Hasalm (2009) had people with mild to severe memory difficulties generate answers to cues such as: “I am thinking of a word that begins with BR, and this word describes food made of flour, liquid, and yeast which is baked and then sliced to make sandwiches. What do you think the word might be?” They found that this method effectively eliminated errors and resulted in better recall than standard errorless learning or effortful learning.

Errorless learning plus self-generation may be particularly effective for people with limited or reduced executive functioning resources because it reduces errors and promotes deeper processing of information, but without the need to self-initiate an elaborative strategy. As previously reviewed, people with limited executive functioning are unlikely to strategically organize and encode information during the initial stages of encoding. This is problematic since elaborating on information during encoding is a “deeper” form of processing that is more durable than more “shallow” forms of encoding (Craik & Lockhart, 1972).

Researchers have argued that errorless learning plus self-generation is a form of deeper processing as it requires greater effort and also activates broader semantic networks associated with the cues (Tailby & Haslam, 2009). In contrast, errorless learning alone represents a more passive form of processing, since the cues are merely read. Indeed, the passivity of traditional errorless learning paradigms is a common criticism of errorless learning, particularly since errorful learning is more active due to the need to generate a guess that could go with the stem. In fact, the original stem-completion paradigm sought to address the passive processing that occurs during errorless learning by having people write down the answer (Baddeley & Wilson, 1994). Other researchers have attempted to equate the depth of processing that occurs during errorless and effortful learning by having participants write sentences using the word in the errorless condition (Hammer et al., 2009). In contrast to these methods, self-generation guides participants through elaboration process (e.g., thinking about attributes of bread) that allows people to arrive at the answer on their own, while also providing multiple cues that may support recall.

Several studies have demonstrated the efficacy of incorporating self-generation into errorless learning, using different patient groups and paradigms. For instance, Lubinsky et al., (2009) found that a group of older adults with mild cognitive impairment benefited most from errorless learning plus self-generation, which was achieved by giving word stems, and as many cues as needed to produce the word independently (e.g., this word is a fruit). Similarly, Guild & Anderson (2012) found that older adults benefited when given cues for word-fragments (e.g., “hop” R_B_IT) as opposed to simply giving them the cue and word, or having older adults first produce a guess. However, self-generation only conferred benefits when the list of words was semantically related, perhaps because the cues facilitated associations between the related words. Finally, Haslam et al., (2017) showed that errorless learning with self-generation is superior to errorless learning or effortful learning in a sample of children with acquired brain injuries, which often include both memory and dysexecutive deficits. However, an earlier study with a similar population showed no added benefit with self-generation (Haslam et al., 2012).

Most studies examining self-generation and errorless learning involve populations that likely have both memory and executive functioning deficits. However, these studies do not include measures of executive capacities, making it difficult to test whether the benefits of self-generation occur by easing the burden on executive functions, or whether the benefits occur due to some other factor. One study has incorporated neuropsychological data to help answer this question. In a group of children with memory-impairments secondary to acquired brain injury, Haslam et al., (2017) included a composite score of digit span forward and backwards, which is considered a measure of attention and executive function. In this study, children learned trivia facts using errorless learning, errorful learning, or errorless learning plus self-generation. They found that self-generation resulted in better cued recall at four different time points. Interestingly, self-generation was the only condition that resulted in improved recall regardless of digit span performance, suggesting that deficits in attention/executive functioning minimally impacted recall following self-generation learning. The authors argue that self-generation bypasses attentional deficits by supporting a deeper level of processing and active learning that generates more durable memory traces. This study suggests that errorless learning plus self-generation may uniquely enhance memory in individuals with limited executive resources, such as people with depression.

Application of Errorless Learning in Depression

The above research suggests that errorless learning principles would likely benefit people with depression, largely by circumventing impaired executive functioning. Notably, errorless learning is likely best applied for people with depression in situations that involve novel associations. This is because errorless learning is generally most beneficial for conceptually unrelated information (Cyr & Anderson, 2012; Evans et al., 2000) and also because people with depression typically struggle most on difficult memory tasks that do not automatically elicit semantic networks and depend more on executive resources to strategically elaborate on and retrieve material (e.g., Lamar et al., 2010). For instance, errorless learning would likely help people with depression complete novel tasks such as learning steps to complete complex computer tasks, learn obscure vocabulary concepts in classroom settings, acquire a second language, and remember the names of peers or coworkers. Prospective memory is also an exciting area for future research given evidence that errorless learning can help people maintain and follow-through on an intention (Fish et al., 2015).

It is also worth noting that in addition to minimizing dependence upon impaired executive function during learning, errorless learning may also prove to be a more rewarding and less frustrating method of study. In several studies, researchers anecdotally observe that patients tend to prefer errorless learning as opposed to effortful learning, perhaps because it results in less failure and more success (Fillingham et al., 2005; 2006). Indeed, Hasalm et al., (2017) observed that children responded more quickly and confidently following errorless learning with self-generation as compared to effortful or standard errorless learning. These observations are particularly relevant for people with depression, as people in depressed moods tend to have heightened emotional sensitivity and negative reactions following errors (Schroder et al., 2013). Therefore, errorless learning with self-generation may be a preferred method of study for people with depression, simply because it reduces the negative emotional impact of errors and generates moments of success.

The Present Investigation

The present study investigated whether people with depression benefit from errorless learning procedures in a stem-completion task. Using a mixed design, all participants learned lists of words using errorless learning (EL), effortful learning (EF), and errorless learning plus self-generation (EL-SG) procedures. Memory was tested using immediate free and cued recall, delayed recall, and a recognition task.

Hypotheses

1. There will be within group main effects of learning condition, with better immediate free, cued, and delayed recall following errorless learning versus errorful learning for both the depressed and control group.
2. There will also be a within group main effect for errorless learning plus self-generation, which will produce better immediate free, cued, and delayed free recall than the errorless learning and effortful learning conditions, in both the depressed and control group.
3. There will be an interaction effect for learning conditions between the depressed and control group.
    a. An interaction will occur in which depressed participants in the effortful condition demonstrate significantly worse immediate free and delayed recall compared to the control group.
    b. An interaction will occur in which depressed participants will benefit more from errorless learning plus self-generation for immediate free and delayed recall, compared to the control group.
4. There will be a main effect for preference, in which both groups indicate subjective preference for errorless learning plus self-generation, as compared to the other two learning conditions.

Online Experiment with MTurk

This study was conducted using a group of depressed and non-depressed participants from mechanical Turk (MTurk). MTurk is a popular crowdsourcing platform in which “workers” are compensated for time spent completing tasks entirely online. In recent years, MTurk has been highlighted as an efficient, reliable, and more diverse source of information compared to college populations (Buhrmester et al., 2011). For instance, MTurk workers tend to be more ethnically and socio-economically diverse (Casler et al., 2013), which presents an advantage in extending the generalizability of behavioral research to broader populations. Furthermore, the quality of the data collected on MTurk appears to be high, with indistinguishable performance observed between in-person computer participants and MTurk workers on common experimental paradigms (e.g., prisoner's dilemma task, priming task) (Horton et al., 2011) as well as cognitive psychology tasks such as list-learning (Kornell et al., 2009; Kornell, 2014).

Despite these advantages, MTurk is not without its pitfalls. High-quality data is typically achieved by carefully screening out "bogus" workers, such as those coming from the same IP address, failures on attention measures, infrequent responses, and failure to answer reliability checks throughout the survey, which can sometimes produce high attrition rates (Ophir, 2019; Contractor & Weiss, 2019). Additionally, MTurk claims that workers with "Masters Qualifications" produce higher quality data, which is granted to workers with high work-completion rates.

The use of MTurk in clinical populations has been recommended by many researchers given the ease with which this population could be accessed online. Recent large-scale studies demonstrate that the rate of psychopathology amongst MTurk workers are higher than the general population, with clinical symptoms of depression ranging from about 1 to 3 times higher than would be expected (Arditte et al., 2016) even with the use of rigorous quality assurance measures (Ophir, 2019). The reason for higher rates of psychopathology has been partially accounted for by life-style variables such as inactivity, rather than demographic variables (Ophir, 2019). Although higher rates of psychopathology present important considerations for generalizability, it also offers a unique opportunity for clinical research, as clinical populations are often difficult to reach through typical university avenues.

To date, clinical psychology research has been conducted with diverse clinical populations. For instance, studies have been conducted with individuals with mild traumatic brain injury (Bernstein & Calamia, 2018), trauma-exposure (Schick et al., 2019), PTSD (Contractor, 2019) suicidality in depression (Cui et al., 2019), and severe mental illness (Umucu et al., 2020). Furthermore, there is some limited indication that experimental studies can be successfully conducted in clinical populations. For instance, experimental studies have been used in the context of cannabis use (Sofis et al., 2020), and a randomized control trial for depression prevention is underway (Kelman et al., 2018).

In summary, MTurk presents an opportunity to conduct efficient, reliable, and high-quality research with diverse populations, that has only recently been extended to clinical populations. Thus, in addition to answering questions about the use of errorless learning in individuals with depression, this study also aims to examine the feasibility of conducting experimental research on MTurk in clinical populations.

Methodology

Participant Selection

This study was advertised on MTurk as an opportunity to take part in memory research. Recruitment materials did not identify depression as a population of interest to ensure that participants were unbiased in their approach to the task (Suhr & Gunstad, 2005). Participants were compensated $.50 if they completed the screener and $10 for completing the learning task, which is well above average compared to similar research (Kornell et al., 2014). After the informed consent, a screener identified participants that met inclusion criteria. The screener included an attention check, demographic questions, health questions, and Patient Health Questionnaire 8-item (Appendix A).

Using G*Power3 (Faul, Erdfelder, Lang, & Buchner, 2007) an a-priori analysis was conducted to test the ability to observe main effects and interactions for a mixed-design analysis of variance (ANOVA) with three within-group levels (EF vs. EL vs. EL-SG) and one between group factor (depression vs. control). A sample size of 114 was required to achieve a power of .80 with a small effect size (f=.12), which is comparable to the effect sizes seen for memory impairments in depressed populations (.17-.21) (East-Richard et al., 2018). However, this study aimed to collect a total sample of 120 participants to account for potential data quality issues and ensure adequate power. Overall, 438 participants provided consent and attempted the screener, with 28.5% completing the full memory task (N=125; Non-depressed N=60; Depressed N=65). Below is a description of exclusion criteria and rationale for participants retained or excluded.

Attention/Quality Assurance

Only MTurk workers granted MTurk Masters Qualification with IP addresses from the United States were included in the study to ensure high-quality data and high completion rates (Ophir, 2019). After the informed consent, participants answered 3 easy multiple-choice questions designed to identify internet bots or random responding (e.g., “I am a human being”) (Clifford et al., 2019). Participants that answered incorrectly were immediately dropped from the study (*N*=1). Two rare health questions (Bells Palsy, Cystic Fibrosis) were used to identify whether participants answered all health questions in the positive direction (i.e., “yes”) to increase their chance of qualifying for the study. No participant endorsed the rare health questions, suggesting participants were attentive to item content. Additionally, no participant scored below 75% correct on the errorless learning condition, which indicates participants were not randomly responding.

Exclusion Criteria

Participants that were 65 years or older (*N*=18), spoke English as a second language (*N*=0) or reported history of a moderate to severe traumatic brain injury (*N*=4) were excluded from the study as these factors are known to impact learning and memory performance. Participants with symptoms of anxiety were retained in the sample, as there are high levels of comorbidity between anxiety and depression in the general population and an ecologically valid sample was desired (Kessler et al., 2003).

Depressed and Non-Depressed Group

The Patient Health Questionnaire 8-item (PHQ-8) identified participants for the depressed and non-depressed groups. The first 60 participants with scores indicating moderate to severe symptoms of depression (PhQ8 $\geq$10) and the first 65 participants with scores indicating mild to no symptoms of depression (PhQ8 <10) were directed to complete the study. Once the quotas were achieved, participants were rejected from the study even if they passed all other screening measures.

To meet the desired quota, 415 MTurk workers that met the inclusion criteria were directed to take the PHQ-8 (80 depressed; 335 non-depressed). Eighty depressed individuals consented to the study, met the above inclusion criteria, and were invited to complete the study. Of the 80 depressed individuals invited, 9.8% (N=8) voluntarily withdrew before the learning trials began, and 12.3% (N=7) withdrew after starting the learning task. The final depressed group consisted of 65 participants.

Of the 335 non-depressed workers interested in the study 75.8% were not invited to complete the memory task as the non-depressed group quota of 60 participants had already been met. In total, 81 non-depressed participants were invited to the study and 16% voluntarily withdrew before the learning trials began (n=13). Additionally, 9.8% non-depressed participants withdrew after they had already started the learning task (n=8). The final non-depressed group consisted of 60 participants.

Design and Procedure

The experimental procedure involved three within-group learning conditions (errorful learning (EF), errorless learning (EL), and errorless learning plus self-generation (EL-SG). Please see Appendix B for the exact wording used in each learning condition. Participants learned three lists of 16 words (Appendix C) one at a time using a word-stem completion task. Instructions to complete a stem were modified depending on the learning condition (e.g., Errorful: "I am thinking of a word that begins with AR, guess that word" vs. Errorless: "I am thinking of a word that begins with AR and that word is Armor" (Baddeley & Wilson, 1994).

Within each of the three learning conditions (EF, EL, EL-SG), participants learned the list twice, for a total of 32 stem-completions per learning condition. In other words, Trial 1 was the initial presentation of the 16 words, and in Trial 2 they were presented with the same 16 word-completion stems for a second time. Immediately following the two learning trials they were tested on their retention of the words using free and cued recall tasks.

After completing one of the learning conditions, they then went on to learn a new list of 16 words using different stem-completion cues. In total, there were 96 learning trials (i.e., 32 per condition). When all three lists were learned and immediate and cued recall tasks completed, participants completed the Generalized Anxiety Disorder 7 Item (GAD-7) questionnaire as a brief distractor task and were then instructed to freely recall all 48 words they had learned over the three conditions in a delayed free recall task. Finally, they completed a “yes-no” recognition task which included all 48 words learned and 48 distractors. At the end of the study, they were asked about their subjective experiences of each learning task. Each of these elements is explained in further detail below.

Learning Conditions

Learning conditions consisted of 16 words each which were elicited using word-stem completion cues. In each set of instructions, they were encouraged to try to remember as many words as they could, as they would be asked to type them in again at a later point in the study.

To control for order effects, the order of conditions was randomized across participants. Additionally, the lists were randomized among the conditions (e.g., *Combination 1:* List A=EF; List B=EL; List C=EL-SG; *Combination 2:* List A=EL-SG, List B=EF, List C=EL,) for six possible combinations. To eliminate order effects for the words within the lists, the stem completion cues were presented in a random order (e.g., List A cues presented in random order over learning Trial 1 and Trial 2).

Errorful learning (EF). (See Appendix B1) In the errorful learning condition participants were presented with a two-letter word stem such as “SN” and asked to guess the word. Because they were given minimal information about the word, it was unlikely that they would freely guess the target word and would instead produce an error. They were informed that the target words would not be proper nouns to increase the chance that errors would be comparable to the target words and produce a more robust interference effect.

For each stem-completion trial, participants were shown a fixation cross for 250ms and then the errorful stem completion cue for 3.5 seconds (e.g., “I am thinking of a 5-6 letter word that begins with “AR” please guess that word). After the cue was presented, they were directed to a response screen and given 25 seconds to type their guess. If their guess was incorrect, a screen informed them their response was incorrect, and they were shown the target word which they were directed to type to ensure accurate encoding of the target words. A green checkmark was shown after they copied the target word and hit “enter.”

It was not anticipated that participants would guess the target word on the first learning trial of the errorful learning condition. However, if participants happened to accurately guess the target word on their first try, a screen informed them they their response was correct, and they were shown an experimenter error. Experimenter errors were included to ensure that each of the first 16 learning trials for errorful learning was associated with an error (e.g., “Correct! The answer is Armor. The answer is not Arrow”). A similar design has been used in other studies (Lubinsky et al., 2009) to ensure that each target word was associated with one error. The current study adopted this approach to avoid dropping items that are correctly guessed in the effortful condition, as has been done in previous online research studies using word lists (Kornell et al., 2009).

The second learning trial was presented immediately after the first and used the same format. However, experimenter errors were not shown in response to correct responses. This was to help maintain the integrity of trail-and-error learning as correct answers in the real-world are rarely met with external errors.

Errorless learning (EL). (See Appendix B2). In the errorless learning condition participants were shown a two-letter word stem and were immediately given the target word that completed the stem.

In the learning trials, participants were shown a fixation cross for 250ms and then the errorless stem completion cue for 3.5 seconds (e.g., “I am thinking of a 5-6 letter word that begins with AR and this word is Armor”). After the cue was shown, they were directed to a response screen and given 25 seconds to type in the target word. If they accurately typed the target word, they were directed to a screen that said “correct!” which was presented for 1000ms.

Given the nature of this learning condition, very few participants were expected to provide incorrect responses in response to the stimulus cue. However, should participants fail to accurately attend to the stimulus cue, corrective feedback was provided, and participants were required to type in the target word to ensure participants attended to each word. The second learning trial was presented immediately after the first and used the same format.

Errorless learning plus self-generation (EL-SG). (See Appendix B3). In the errorless learning plus self-generation condition, participants were shown a semantically rich clue to help complete the stem with minimal errors (Appendix D).

In the self-generation learning trials, participants were shown a fixation cross for 250ms and then the self-generation stem completion cue for 25 seconds (e.g., “I’m thinking of a 5-letter word that begins with AR and this word describes metal coverings formerly worn by soldiers or warriors to protect the body in battle”). Participants were allowed to proceed to the response screen before the 25 seconds had passed if they knew the answer. This was done to provide ample time for participants to read to clue, while also attempting to shorten the amount of time the self-generation cue was presented to match the other two learning conditions (3.5 seconds).

Correct responses to the cue directed participants to a screen that said they were correct (e.g., “Correct! The word is Armor”). Incorrect responses directed participants to a screen that showed them their incorrect response and provided them with the target word (e.g., “you answered ‘Arena’, which is incorrect, the correct answer is Armor”). They were instructed to type in the target word before they could proceed to the next screen. The second learning trial was presented immediately after the first and used the same format.

Immediate Free and Cued Recall

Immediately after participants completed two trials of a learning condition, they were asked to freely recall as many words as they could remember, in any order. Words were typed in one at a time, and no feedback was given as to whether responses were correct or incorrect. (Appendix E1).

After immediate free recall was complete, participants were directed to complete an immediate cued recall task (Appendix E1). The sixteen-word stems from the list just learned (e.g., “AR”, “CL”) were presented in random order, one at a time, and participants were instructed to complete the stem from memory. They were given the option to skip the item if they could not remember the word to limit frustration and prevent errors in the two errorless conditions. After completing both immediate recall tasks, they were directed to learn another list of words until all three lists of 16 words were learned.

Delayed Recall

Following the three learning conditions and immediate recall tasks, participants completed the GAD-7 (Appendix F) to provide a brief distraction to counter recency effects for delayed recall.

For delayed recall, participants were instructed to think back to the first list they had learned and to type in as many words as they could remember from the first list (Appendix E2). If participants could think of a word, but not the list that it went with, they were instructed to type the word anyway. This caveat was included as this study was primarily interested in number of words recalled rather than strength of source memory. Participants were given the same instructions for the second and third lists of words learned. After recalling words from all three lists, they were directed to a fourth response screen that encouraged them to type in any words that they recalled but had not yet typed. Again, this was intended to ensure that participants provided all words remembered. No feedback was given as to whether responses were correct or incorrect.

Following delayed free recall, participants were directed to the recognition task (Appendix E3). In the recognition task they were shown 96 words (48 target words, 48 distractor words) and responded “yes” if they were asked to remember that word earlier and responded “no” if they were not asked to remember that word. The distractor words consisted of 48 new distractor words that the participant had not seen but had the same two-letter stems as the target word list (Appendix E4).

Learning Preference

At the very end of the study, participants were asked which learning condition they preferred (Appendix G). Examples were given of each learning condition, and they rated how much they liked that way of learning on a Likert scale with 1 indicating “I did not like this way of learning” and 7 indicating “I really liked this way of learning.” They were then asked to rank the learning methods from most preferred to least preferred. Finally, participants were given the option to provide qualitative feedback to the examiner.

Mental Health Resources & Debrief

At the end of the study all participants were provided links to national mental health and suicide hotlines, in case mood questionnaires or the learning task elicited negative affect

(Appendix H). They were then debriefed on the purpose of the experiment and given a completion code to claim their compensation for the study.

Materials

Word Lists

Target Words.

Three wordlists of 16 words were created for the purposes of this study (Appendix C). Like prior research, words consisted of 5-6 letter nouns, and word stems were only used once (e.g., BR, CO, TR). Words with an affective component (e.g., “coffin”) were eliminated to avoid biased information processing in the depressed group.

Previous errorless learning research in populations with mild memory impairments observed ceiling effects with a list of 12 words (Tailby & Hasalm, 2003). Therefore, the current study extended the word list to 16 words to increase the difficulty of the task and avoid ceiling effects. Additionally, words that had low frequency and accessibility indices were selected from Nelson et al., (2004) to increase task difficulty. The frequency index measures how common the word is in everyday speech in the United States, and the accessibility index describes the interrelatedness to other words and semantic networks (e.g., “money” has a high association correlate). High frequency and accessibility have been shown to facilitate free recall performance (Rubin & Friendly, 1986). Therefore, this study restricted the word lists to nouns below the top quartile (i.e., 75th percentile and below) for frequency and accessibility to increase the difficulty of the word list.

Forty-eight words derived using the above criteria were distributed to 3 lists (Lists A, B, & C). Words from the same category (e.g., food, animals) were distributed evenly among the lists to avoid generating associative networks within each list. Analyses were conducted to ensure that the 3 lists had comparable frequency and accessibility indices. A one way analysis of variance (ANOVA) revealed no significant group differences for frequency *F*(2,47)=.193, *p*=.66 with similar means for all three target word lists (List 1 *M*=11.8, *SD*=9.9; List 2 *M*=12.1, *SD*=13.2; List 3 *M*=10.4, *SD*=12.6). Likewise, a one-way ANOVA revealed no significant group differences for accessibility *F*(2,47)=.032, *p*=.96 with similar means between target word lists (List 1 *M*=7.8, *SD*=4.2; List 2 *M*=8.1, *SD*=4.3; List 3 *M*=7.8, *SD*=4.8).

Experimenter Errors.

In addition to the target word list an "experimenter error" list was constructed with words that have the same beginnings as the target list (e.g., the target word "armor" has the experimenter error "arrow") (Appendix C). Experimenter errors were introduced if the participant guessed the target word in the errorful condition. For instance, if the participant guessed the target word "armor" in the effortful condition, they were told "correct! The word is armor. The word is not arrow." It is important to note that the experimenter errors were only used in the effortful condition and not in the two errorless learning conditions.

Experimenter errors were selected that had similar frequency and accessibility indices as the target word list (Appendix B). A series of independent samples t-tests show no significant difference in frequency for target and experimenter errors for list A *t*(30)=.-.805, *p*=.455, list B *t*(30)=-.504, *p*=.15 or list C *t*(30)=-.973 *p*=.83. Similarly, there are no between group differences for accessibility using independent samples t-tests for List A *t*(30)=.-.426, *p*=.77, List B *t*(30)=-.586, *p*=.94, or List C *t*(30)=-.216 *p*=.65, as compared to their experimenter error list. These analyses suggest that experimenter errors are comparable in frequency and accessibility to the target words.

Self-Generation.

For the errorless learning plus self-generation condition, semantic cues were created for each target word that could reliably elicit the correct answer (Tailby & Hasalm, 2004) (see Appendix C). For instance, for the target word "armor" the following clue was used: "I'm thinking of a 5-letter word that begins with AR and this word describes metal coverings formerly worn by soldiers or warriors to protect the body in battle."

Sixty-five words were piloted with 10 MTurk workers but did not produce 100% accuracy, which was unacceptable for the purposes of this study. Semantic clues were modified, and an additional 10 MTurk workers answered the questions until 100% accuracy was achieved for 48 target words and clues. MTurk workers were compensated $.50 for their time and completed informed consent. Please see Appendix D for the clues used for each list. Workers that piloted the self-generation words were excluded from the present study.

PHQ-8

The Patient Health Questionnaire 8-Item (PHQ-8) is a self-report questionnaire comprised of items that describe depression symptoms (Kroenke et al., 2001) (Appendix A4). Each item is rated on a 0–3-point scale, with higher scores indicating more severe symptoms. Total scores range from 0-24 and scores greater than or equal to 10 represent moderate levels of depression severity (Shin et al., 2019). The current study eliminated the item assessing for suicidality (Item #9) as the nature of online research prohibits assessing for suicidal intent and ensuring participant safety if a participant endorses this item.

Research with the PHQ-8 has demonstrated excellent internal reliability (α=.89). Additionally, there is good construct and discriminant validity (Shin et al., 2019). Moreover, the

PHQ has been utilized in other studies using an MTurk population (e.g., Cui et al., 2019; Ophir et al., 2019).

GAD-7

The Generalized Anxiety Disorder 7-item (GAD-7) is a 7 item self-report questionnaire comprised of items that capture anxiety symptoms (Spitzer et al., 2006) (Appendix F). Each item is rated on a 0–3 point scale, with higher scores indicative of more severe symptoms. Total scores range from 0-21 with scores greater than or equal to 10 representing moderate levels of anxiety. Research with the GAD-7 has demonstrated excellent internal reliability (α=.92) and excellent test-retest reliability (α=.83). There is also good construct and discriminate validity.

Results

Participant Characteristics

One-hundred and twenty-five participants took part in the study with 53.6% identifying as female (N=67; Male N=58). Participants had a mean age of 42.3 (*SD*=10.2, Range 23-64) and mean education of 15.0 years (*SD*=1.9, Range 11-20). Eighty-four percent of participants identified as white (N=105), 6.4% as black or African American (N=8), 4.8% as Asian or Pacific Islander (N=6), 4% as multi-or bi-racial (N=5) and 0.8% as Native American (N=1). Each participant completed the task in a single session (*M*=36 mins, *SD*=8.2).

A chi-square analysis showed that the proportion of participants choosing to withdraw did not differ depending on depression status, X^2(N=1)=1.451, *p*=.484 which argues against selection bias for depression status in this sample.

A series of independent samples t-tests examined whether the depressed and non-depressed groups differed from each other on selective demographic variables known to impact memory performance. The groups did not differ in years of education, or the amount of time spent completing the study (Table 1). Unexpectedly, the depressed group was significantly younger than the control group. As a result, this study opted to include age as a co-variate in the proposed analyses of immediate free, cued, and delayed recall to control for the impact of age differences on memory performance, which are reported below. As expected, the depressed group had higher scores on the PHQ-8 compared to the control group.

Table 1

Demographic Differences by Depression Status

	Non-depressed (N=60)	Depressed (N=65)	t (1,123)	p-value
Age	44.75(10.64)	39.98 (9.43)	2.65	.009*
Education	15.27 (1.93)	14.88 (1.87)	1.14	.254
Time to Complete Study (mins)	36.97 (8.72)	35.40 (7.80)	1.062	.290
PhQ8-Depression	2.52 (2.90)	13.77 (2.94)	-21.5	<.001*
*Significant difference; Patient Health Questionnaire 8 Item (PHQ8)				

Descriptive Statistics: Performance of Both Groups on Memory Task

Descriptive statistics demonstrated that each condition fell within expectations for number of correct answers for each learning trial, regardless of depression status (see Table 2). Descriptive statistics also examined the time it took to complete each condition (see Table 3).

Table 2

Number of Target Words Recalled on Learning Trials as a function of Depression Status

	Trial 1 Mean (SD)		Trial 2 Mean (SD)	
	Non-Depressed	Depressed	Non-Depressed	Depressed
Errorful Learning	1.12 (1.06)	1.12 (1.11)	7.95 (3.81)	8.09 (3.36)
Errorless Learning	15.5 (0.37)	15.8 (0.19)	15.9 (0.44)	15.8 (0.36)
EL-Self Generation	15.8 (0.93)	15.8 (0.34)	15.8 (0.60)	15.9 (0.35)

Table 3

Number of Minutes to Complete T1&T2 as a function of Learning Condition and Depression Status

	Time to Learn in Minutes Mean (SD)	
	Non-Depressed	Depressed
Errorful Learning	7.53 (1.74)	7.27 (1.11)
Errorless Learning	5.17 (0.78)	5.01 (0.65)
EL-Self Generation	7.19 (1.93)	6.51 (1.33)

Error Analyses for Errorful Learning Condition

Participant Errors.

Participant errors are the number of errors that participants freely made during Trial 1 and Trial 2 of the EF learning trials. Intrusions of participant errors on subsequent recall tasks occurred but were generally rare (Table 2).

Experimenter Errors

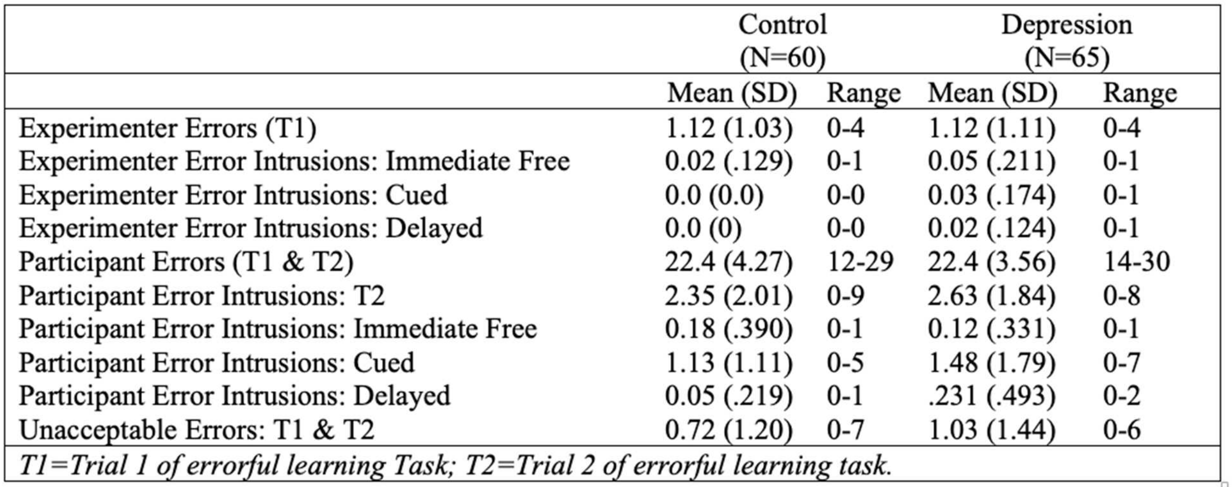
Experimenter errors were induced errors given to participants if they correctly guessed the word on trial 1 of errorful learning. Number of experimenter errors correlated with stronger immediate free recall $r(125)=.176$, $p=.05$ and stronger immediate cued recall performance, $r(125)=.200$, $p=.026$ but did not correlate with delayed recall $r(125)=.095$, $p=.291$. This pattern suggests that there was some advantage conferred when participants accurately guessed the word on the first trial of errorful learning. Intrusions of experimenter errors were extremely rare, with only five participants producing errors (Table 2).

Unacceptable Errors.

Unexpectedly, the experiment also produced “unacceptable” errors for all learning conditions (Table 2). Unacceptable errors included nonwords, stems only, a choice to skip, intrusions from earlier in the list, or words that had the wrong stem entirely. Overall, 52% of the sample made no unacceptable errors (N=66), and 48% made 1 or more (range=1-7). Individual examination of extreme cases did not demonstrate consistently poor performance across the memory task for participants that made multiple unacceptable errors. Because this study did not account for unacceptable errors in the initial hypotheses, and the mechanism driving unacceptable errors are unclear, these participants were kept in the sample.

Table 2

Number of Errors as a Function of Depression Status



	Control (N=60)		Depression (N=65)	
	Mean (SD)	Range	Mean (SD)	Range
Experimenter Errors (T1)	1.12 (1.03)	0-4	1.12 (1.11)	0-4
Experimenter Error Intrusions: Immediate Free	0.02 (.129)	0-1	0.05 (.211)	0-1
Experimenter Error Intrusions: Cued	0.0 (0.0)	0-0	0.03 (.174)	0-1
Experimenter Error Intrusions: Delayed	0.0 (0)	0-0	0.02 (.124)	0-1
Participant Errors (T1 & T2)	22.4 (4.27)	12-29	22.4 (3.56)	14-30
Participant Error Intrusions: T2	2.35 (2.01)	0-9	2.63 (1.84)	0-8
Participant Error Intrusions: Immediate Free	0.18 (.390)	0-1	0.12 (.331)	0-1
Participant Error Intrusions: Cued	1.13 (1.11)	0-5	1.48 (1.79)	0-7
Participant Error Intrusions: Delayed	0.05 (.219)	0-1	.231 (.493)	0-2
Unacceptable Errors: T1 & T2	0.72 (1.20)	0-7	1.03 (1.44)	0-6

T1=Trial 1 of errorful learning Task; T2=Trial 2 of errorful learning task.

Memory Performance

Immediate Free Recall

As proposed, a mixed-design repeated measures analysis of co-variance (ANCOVA) examined hypotheses 1-3. The between-subjects factor was depression status (depressed vs. non-depressed) and the within-subjects factor was immediate free recall for each learning condition (EF vs. EL vs. EL-SG). Age was included as a covariate to control for the age differences in the two groups. Preliminary analyses indicated that the model meets the assumption of homogeneity of regression, $F(1,121)=1.62$, $p=.204$.

Analyses revealed significant main effects for learning condition, $F(2, 244)=3.34$, $p=0.027$, $\eta^2=.027$ while controlling for age. Consistent with hypothesis 1, paired sample t-tests with Bonferroni corrections revealed that participants recalled significantly more words in the

EL condition compared to the EF condition (Table 3). Consistent with hypothesis 2, the EL-SG group produced significantly stronger immediate free recall performance compared to both the EF and the EL condition.

Contrary to hypothesis 3, there was no interaction effect between learning condition and depression status, *F*(2, 244)=.502, *p*=.606, η^2=.004. There was also no between-subject effects for depression status, *F*(1,122)=.609, *p*=.437, η2=.001, suggesting that both groups had similar memory abilities.

Table 3

Immediate Free Recall Post-hoc Analyses for Main Effects

	Mean (SD)	Comparisons	Confidence Interval	*P* value
EF	8.31 (3.19)	EL versus EF	1.053(CI, .385, 1.721)	.001*
EL	9.38 (3.78)	EL-SG vs. EF	1.87(CI, 1.24-2.5)	<.0001*
EL-SG	10.19 (3.38)	EL-SG vs. EL	.821(CI, .199-1.44)	.005*

**significant <.05, ns= non-significant*
EF=Errorful Learning, EL=Errorless Learning, EL-SG=Errorless Learning plus Self-Generation

Immediate Cued Recall

An ANCOVA with cued recall as the within-group dependent variable (EL vs EF vs EL-SG) and depression status as the independent variable, was used to test the first three hypotheses. Age was included as a covariate. Preliminary analyses indicated that the model meets the assumption of homogeneity of regression, *F*(1,122)=1.44, *p*=.204. The test of sphericity was violated so the Greenhouse-Geiser correction was used.

A significant main effect was observed for learning condition, *F*(2, 229) =4.53 *p*=.013, η^2=.036 while controlling for age. Tests of proposed hypotheses were conducted using paired sample t-tests with Bonferroni corrections (Table 4). Contrary to hypothesis 1, there was no significant difference between cued recall performance in the EL condition compared to the EF condition. However, as expected per hypothesis 2, the EL-SG group had significantly stronger cued recall compared to both the standard EL and the EF condition.

Contrary to hypotheses 3, the interaction between cued recall performance and depression status was not significant, *F*(2, 229)=.352, *p*=.690, η2=.003 suggesting that depression status did not differentially impact recall performance in any of the three learning conditions. Between-subject effects for depression status was not significant, *F(*1, 122)=1.35, *p*=.228, η2=.012.

Table 4

Immediate Cued Recall Post-Hoc Analyses for Main Effects

	Mean (SD)	Comparisons	Confidence Interval	*P* value
EF	11.18 (3.19)	EL versus EF	104(CI, -.566-.793	*ns*
EL	11.29 (3.79)	EL-SG versus EF	1.76(CI, 1.06-2.47)	<.0001*
EL-SG	13.06 (2.79)	EL-SG versus EL	1.87(CI, 1.31-2.44)	<.0001*

**significant <.05, ns= non-significant*

EF=Errorful Learning, EL=Errorless Learning, EL-SG=Errorless Learning plus Self-Generation

Delayed Free Recall

As above, a mixed-design ANCOVA was used to test hypotheses 1 to 3, with depression status as the between-group factor, and delayed recall performance on the three learning conditions as the within-group factor. Age was included as a co-variate. Preliminary analyses indicated that the model meets the assumption of homogeneity of regression, *F*(1,121)=2.21, *p*=.139.

Contrary to hypotheses 1 and 2, there were no main effects for learning condition, *F*(2,244)=.084, *p*=.920, η2<.001. As a result, no post-hoc analyses were conducted. In contrast to hypothesis 3, there was no interaction effect between depression status and delayed free recall performance, *F*(2,244)=.484, *p*=.617, η2=.004. The depressed and non-depressed group did not differ in delayed memory performance with no between-subject effects, *F(*1,122)=.435, *p*=.435, η2=.005.

Recognition Performance

No hypotheses were generated for recognition recall because between-group differences or main effects were not expected for recognition performance. Thus, an exploratory mixed-design ANOCVA examined whether any unexpected differences emerged between the groups for recognition. Tests of model assumptions indicated that the model meets the assumption of homogeneity of regression, $F(1,121)=2.22$, $p=.139$.

There were no within-group main effects for learning condition, $F(2,244)=0.084$, $p=.920$, $\eta 2<.001$. Additionally, there were no interaction effects for recognition recall and depression status, $F(2,244)=.484$, $p=.617$, $\eta 2=.0.12$. Between-group effects for depression status was not significant, $F(1,122)=.040$, $p=.841$ $\eta 2<.001$.

Exploratory Analyses for Time Effects

Paired samples t-tests showed that regardless of condition, delayed recall performance was strongest for the third list learned, which suggests possible recency effects due to procedures used in the present study (Table 5).

Table 5

Effect of List Order on Number of Words Learned

	Mean (SD)	Comparisons	*t*(124)	*P* value
First list learned	6.5 (3.9)	1st versus 2nd	.236	.814
Second list learned	6.4 (4.3)	1st versus 3rd	2.08	.039*
Third list learned	7.3 (4.4)	2nd versus 3rd	2.02	.046*
**significant <.05, ns= non-significant*				

Learning Method Preference

Ranked Preference

To test hypothesis 4, a Friedman one-way ANOVA, non-parametric test was performed with participant rankings (1-3) for each learning condition as the dependent variable and depression status as the independent variable. As anticipated, participant ranks differed significantly between the three learning conditions, $X^2(2, N=125)=117.6, p<.0001$. An examination of means using post-hoc Wilcoxon signed rank tests, indicates that participants tended to rank EL learning higher than EF learning (Table 6). Moreover, consistent with hypothesis 4, EL-SG learning was ranked higher than both EF learning and EL learning conditions.

Table 6

Ranked Preferences as a Function of Learning Condition

	Mean (SD)	Median	Comparisons	Wilcoxon ranks	*P value*
EF	2.55 (.65)	3	EL versus EF	T=5045, z=-2.948	.005*
EL	2.22 (.63)	2	EL-SG versus EF	T=7429, z=-8.87	<.0001*
EL-SG	1.23 (.49)	1	EL-SG versus EL	T=877, z=-7.94	<.0001*

**significant <.05, ns= non-significant*
EF=Errorful Learning, EL=Errorless Learning, EL-SG=Errorless Learning plus Self-Generation

Scaled Likeability

To further test hypothesis 4, mixed-design ANOVA was used with depression status as the independent variable and Likert scale likeability ratings for the three conditions as the dependent variable (EF vs. EL. Vs. EL-SG). As expected, there was a main effect for learning preference $F(2,246)=89.9, p<.0001$. Paired samples t-tests with Bonferroni corrections indicated that participants rated EL learning as more likeable than EF learning (Table 5). Additionally, as predicted in hypothesis 4, EL-SG learning was rated as more likeable than both the EL and EF conditions.

Table 5

Post-Hoc Analyses of Main Effect for Task Likeability

	Mean (SD)	Comparisons	Confidence Interval	*P* value
EF	3.34 (1.7)	EL versus EF	.951(CI, .42-1.47)	<.0001*

EL	4.30 (1.6)	EL-SG vs. EF	1.76(CI,1.30-2.24)	<.0001*
EL-SG	6.05 (1.4)	EL-SG vs. EL	2.71(CI,2.21-3.22)	<.0001*

EF=Errorful Learning, EL=Errorless Learning, EL-SG=Errorless Learning plus Self-Generation
**significant <.05, ns= non-significant*

Qualitative Feedback

Hypotheses were not generated for qualitative feedback. However, a general overview of participant feedback is included to serve as a guide for future experimental research projects on MTurk and give a general sense of how participants reacted to the study. In total, 26% of participants opted to offer qualitative feedback, as it was optional. Fourteen participants shared that the study was either enjoyable (e.g., “I really enjoyed this study and found it to be challenging, but a lot of fun”) or ran smoothly (e.g., “great survey”). Six participants shared their preference on what kind of learning task they enjoyed most (e.g., “I didn’t like guessing the word because it introduced extra words or extra “clutter” into my mind that may have affected my learning of the words”).

Six participants shared that they felt they did a bad job on the task (e.g., “I really tried, my memory is so bad, I feel bad, I’m sorry”). Five participants shared that they wished the design of the study was different (e.g., “[On free recall] I would have liked to be able to see what words I had already typed, so that it would help me recall the other words in each group.”). Three participants shared that they spontaneously used a strategy, (e.g., “I tried to envision it like giving thumbs up to a sheep holding a hanger. It worked differently depending on how the list was presented”). Finally, three simply said “thanks” for the study.

Discussion

Despite a plethora of research showing the consequences of cognitive deficits in depression (Goodall et al., 2018, Snyder, 2013, Jaeger et al., 2006), research for cognitive interventions in this population is sparse (e.g., McIntyre et al., 2015 for review). Verbal memory deficits are common in depression and are largely driven by impaired executive functioning abilities (Snyder, 2013). Therefore, a primary target for the development of successful memory interventions for this population should be executive functioning abilities.

Errorless learning is a cognitive rehabilitation technique that may bypass the need to rely on executive functioning abilities by eliminating the need to identify errors, inhibit them during retrieval (Clare & Jones, 2008) and spontaneously elaborate on information (Hertel 2000). As a result, this study examined whether errorless learning procedures would help people with depression compensate for verbal memory deficits by reducing the burden on impaired executive functions. Additionally, this study examined whether the addition of self-generation procedures, in which the target is elicited through semantic clues, would provide additional benefit for individuals with depression by facilitating better elaboration. Finally, participant's subjective experiences of different learning methods were examined, as this has not yet been examined in the literature.

Depression Status and Memory

Contrary to proposed hypotheses, there were no interaction effects observed between condition and depression status overall. Examination of means shows that while the depressed group had descriptively lower memory performances for immediate free, cued, and delayed recall, these differences were not significant in between-subject analyses. In other words, the depressed and control groups had similar memory abilities, which eliminates the possibility of observing proposed interaction effects. While the interaction effects were nonsignificant, this study nonetheless showed strong main effects for EL and EL-SG learning, regardless of depression status, which was consistent with proposed hypotheses. These findings replicate research showing benefits of errorless learning in non-clinical samples (Hasalm, Hodder & Yates, 2011; Anderson et al., 2012, Hammer et al., 2009, Hammer et al., 2011), while also extending that research to a sample that reports moderate to severe symptoms of depression. Additionally, this study extends the literature on errorless learning by providing the first examination of participant preference for learning style, with the sample largely ranking EL-SG over both EF and EL learning procedures. Each of these findings will be discussed below.

Errorless Learning Advantage

The first aim of the present study was to replicate previous research demonstrating that errorless learning procedures outperform trial-and-error learning for information that is not conceptually related. Results confirmed that for depressed and non-depressed populations, errorless learning improves immediate free recall performance but did not benefit recall for tasks of cued and delayed recall.

Errorless Learning Immediate Recall

The main effect observed for immediate free recall is consistent with some studies showing the benefits of EL learning (Hunkin et al., 1998, Hasalm et al., 2011, Anderson et al., 2012, Lubinsky et al., 2009) but not with others (Page et al., 2006, Evans et al., 2000, Fish et al., 2015). The mixed findings regarding free recall in the literature has resulted in a lively debate about the mechanisms of errorless learning. More so than cued recall, free recall is an explicit memory task as it requires people to recall the details of the initial learning episode which is a conscious process (as opposed to implicit memory which is regarded as “unconscious”). Additionally, as compared to cued recall, free recall requires the ability to exert effortful search strategies to locate and recall memories (i.e., executive functioning) (Hayes et al., 2011). Therefore, differential performance on free recall tasks has been used to identify the mechanism of the EL advantage. In general, increased performance in free recall under EL learning methods indicates (1) explicit memory has been enhanced by eliminating the need to differentiate between error and target and (2) the burden on executive functioning has been relieved by eliminating the need to inhibit errors (see Hunkins et al., 1998 and Clare & Jones, 2008 for summary of these theories). Both theories share the idea that cognitive resources are limited and that reducing the burden on cognitive resources during encoding or retrieval produces stronger memory performances.

Given the importance of free recall as an outcome measure, the current finding of an EL advantage on immediate free recall lends support to the argument that errorless learning helps facilitate explicit memory systems and limits the burden on executive functions. Importantly, the control and depressed groups did not differ in their ability to perform free recall tasks, which is a standard measure of explicit memory, with the sample's performances generally above zero (means ranged from 6-10/16). This shows that explicit memory was intact for both groups, which is unsurprising, as participants with depression have intact memory systems, albeit mildly impaired (Burt, Niederehe, & Zembar, 1995; Rock et al., 2014; Neu et al., 2001; 2005). Given that EL learning helped improve existing cognitive abilities in a healthy and depressed population, the mechanism for that change is most likely through an explicit (Hunkins et al., 1998) or executive mechanism (Hammer et al., Scheper) rather than depending upon implicit memory systems, as would be seen in severely impaired populations (Baddeley & Wilson, 1994).

Moreover, this study showed a pattern of responses that lends additional support to the executive hypothesis. Interestingly, as described in the error analyses reported above, participants that made less errors on Trial 1 of the EF learning condition were more likely to have stronger performances on immediate free recall. This pattern unintentionally revealed a dose-response relationship between errors and recall, which theoretically aligns with the notion that errors are detrimental because of the burden they place on executive functioning (i.e., error-monitoring, inhibition) (Clare & Jones, 2008). In this study, when the burden of errors was slightly relieved through (lucky) correct guesses on the first trial of the EF condition, performance on immediate free recall subsequently improved. This is consistent with research showing a dose-response between number of errors during encoding and subsequent memory performance (Hammer et al., 2013). The positive relationship between accurate first guesses and recall performances could also function through another executive mechanism, such as the unexpectedness of getting the answer correct, which could generate more attention and therefore better retention for that word (Zawadzka & Hanczakowski, 2018). Finally, although intrusion errors were rare, the intrusions of previous errors under errorful learning conditions demonstrates failures of executive functioning to inhibit errors (Fillingham et al., 2005) which could be driving the observed costs of errorful learning in the present study.

Overall, the positive relationship of Trial 1 correct errors with recall performances, combined with the generation of intrusion errors, suggests that the errors produced during EF procedures produces an interference effect that disrupts immediate free recall. As hypothesized, eliminating the interference of errors through EL learning facilitates stronger memory traces for free recall in a group that reports moderate to severe symptoms of depression, and a group of healthy controls.

Errorless Learning Cued Recall

The lack of difference between EL and EF for cued recall is surprising, as cued recall is most used in EL paradigms and consistently show benefit from EL learning procedures as compared to EF learning procedures (Baddely & Wilson, 1994, Cyr & Anderson, 2014, Hasalm et al., 2012, Hasalm et al., 2011, Evans et al., 2000). The proposed hypothesis assumed that EF learning would negatively impact immediate cued recall, as cues presented during retrieval (e.g., “AR”) could elicit intrusion errors that would lower recall performance. Consistent with that, cued recall generated intrusion errors in the EF condition, with 70% of the sample making at least one intrusion error on cued recall (*M*=1.31).

Despite more intrusions on cued recall than free recall, there was not a meaningful difference observed between EF and EL cued recall performances. At first glance, this seems to contradict the executive hypothesis, as intrusion errors theoretically reflect lapses in inhibitory control and should produce poorer performance for the EF condition compared to EL learning (Clare & Jones, 2008, Fillingham et al., 2005). However, the procedures for the present study may have inadvertently created a difference in the learning environments of EF and EL conditions that impacted the burden on executive functioning in the cued recall task.

One explanation for the lack of significant difference between EL and EF cued recall performances involve the procedures used for the present study. Most stem-completion research is conducted in-person, with a slight pause added between the cue and the answer for the EL condition (Baddely & Wilson, 1994). For instance, Lubinsky et al., (2009) had experimenters say, “I am thinking of a word that begins with BAN” and then pause before saying, “and it is a banana.” This forces the participant to first hear and attend to the stem, and then hear the target word. In contrast, the computer procedures for the present study had the stem cue and target word presented as one item on a screen for 3.5 seconds, “this is a word that begins with AR and the word is Armor.” Unfortunately, participants may not have attended to the stem and attended only to the target word. In contrast, in the EF condition participants were shown the cue “AR” and were asked to generate a 5-6 letter word with that beginning, which requires participants to more actively interact with the cue to find an appropriate word. The executive hypothesis argues that the EL benefit occurs by reducing the burden on attentional systems by eliminating the interference of errors (Clare & Jones, 2008), however, this study may have reduced the attentional burden of EL to such a degree that all the information needed to support cued recall was not encoded (i.e., looking at stems). Indeed, Craike & Lockhart (1972, 1975) show that information is more likely to be remembered when the testing environment mimics the learning environment. As a result, the EL group may have performed more poorly when presented with cues, because participants did not attend to cues during learning. This interpretation is consistent with the observed results that EL learning produced better immediate recall, because there were no cues presented to guide retrieval for the EF group.

The possibility that this study set up poor attention for the recall cue is consistent with a common criticism of EL learning, which is that EL learning lacks “active” participation and limits the generalizability of information learned as participants cannot learn from mistakes (Zawadzka & Hanczakowski et al., 2018). For instance, in a series of experiments with healthy adults Jones et al., (2010) demonstrated that the errors made on an anagram task facilitated performance on a similar task because participants learned how to respond more efficiently due to their prior errors and developed better attentional strategies, as compared to EL learning.

Along those same lines, the errors generated during the EF learning trials in the present study could have facilitated cued recall performances by providing “stepping-stones” to the correct answers. These researchers argue that in some cases errors occurring during encoding facilitate stronger recall. For instance, in an EL paradigm using word-pairs, Anderson et al., (2014) found that when older and younger adults were forced to recall the error they had made, they more easily remembered the target word, although this effect only occurred for conceptual information rather than lexical. While the current study used lexical information, a similar process could be at play, wherein participants in the EF condition saw the cue, remembered their prior error, which acted as a "bridge" to the correct answer. Other researchers argue that getting answers wrong generates more memorable, emotional responses that subsequently facilitate recall (Kornell et al., 2009).

Notably, using errors as "stepping-stones" to the answer takes considerable executive control, and may only work for individuals with intact executive functions (Anderson et al., 2014). This could have been possible for participants in this sample given the level of education overall (*M*=15.0) and the lack of cognitive differences observed between the depressed and non-depressed groups. While this is an interesting possibility, the means between EF and EL cued recall remain statistically equal, which argues that even if there was facilitation from the errors that facilitation did not create stronger memory traces than the elimination of errors.

Overall, the lack of difference in cued recall performance for the present study contradicts previous literature but lends support to theories that the nature of the learning environment impacts recall. Clinically, this implies that information should be learned in a manner that is similar to the demands of recall to optimize recall performance, which is a well-accepted principle in memory research (Craike & Lockhart, 1975).

Errorless Learning Delayed Recall & Recognition

Contrary to expectations, participants did not have stronger EL delayed recall compared to EF delayed recall. Few errorless learning paradigms include a delayed free recall condition, and evidence for the durability of EL learning over a delay is mixed. Some studies show benefits of EL over a delay (Hasalm et al., 2017, Hasalm et al., 2011, Lubinsky et al., 2009) and others show that the benefits of EL learning are short-lived (Squires et al., 1997; Evans et al., 2000, Hasalm et al., 2011) and can even be inferior to the durability of material learned during trial-and-error learning (Hunkin et al., 1998).

The current study found no differences between the EL and EF learning conditions after a short delay. Exploratory analyses showed that delayed recall was subject to recency and time effects which likely limited the ability to accurately see the impact of learning method on delayed recall. Recency effects is a phenomenon in which the last 3-4 items presented tend to be recalled first and accurately. After 30 seconds recency effects disappear (Glanzer et al., 1966) and are no longer considered to be in held in short-term working memory (Atkinson & Shiffrin, 1968). In this study, the GAD-7 took an average of 17 seconds to complete (SD=1.5) with delays ranging from 5 to 72 seconds, and most participants falling below the 30 second required mark. This delay is much shorter than that used in studies showing a difference between EL and EF learning which tend to range between 5–8-minute delays (Squires et al., 1997), and up to a 24-hour delay (Haslam et al., 2017). This study attempted to control for recency effects by having participants recall words from the first list learned which was temporally further than lists 2 and 3. However, in some cases participants simply recalled all the words remembered, in any order, which were not controlled for in the analyses. In support of recency effects for the present study, statistical analyses demonstrated that significantly more words were recalled from the third list learned (*M*=7.3) as compared to the first list learned (*M*=6.5). This is a procedural issue that could be solved by ensuring an adequate delay between the learning tasks and delayed recall.

In addition to recency effects, there could be an effect of time more generally, as the first list of words was learned an average of 18.7 minutes before delayed recall, whereas the third list was only subject to a 17” delay, depending upon whether participants followed instructions to recall words in the order learned. It is well-known that forgetting occurs on a temporal gradient, with more forgetting occurring over time. Therefore, information from the first list was likely more difficult to recall because of the temporal distance between the first learning condition and the delayed recall task.

Finally, recognition recall showed no main effect for learning condition, which is unsurprising since recognition is considered a more automatic process that depends less on the ability to inhibit errors and does not require effortful search attempts as the words are presented to participants (e.g., Fossati et al., 2004).

Self-Generation Advantage

The second hypothesis sought to establish that self-generation produces stronger memory traces over standard errorless learning and effortful techniques. Consistent with prior research, the self-generation condition produced significantly better recall performances for immediate and cued recall (e.g.,Tailby & Hasalm, 2009, Lubinsky et al., 2009, Hasalm et al., 2017) compared to the other two conditions. Moreover, this benefit was demonstrated in a sample with moderate to severe symptoms of depression, as well as healthy controls.

The self-generation paradigm used in this study is a newer addition to errorless learning procedures, but the theoretical underpinnings are old, as deeper levels of semantic processing are known to enhance memory at recall (Craike & Lockhart, 1972). Self-generation is considered an errorless learning procedure because it minimizes errors during the initial stages of learning by eliciting the correct answer with semantically rich cues. While this study did not completely eliminate errors for the self-generation condition as in other studies (Tailby & Hasalm, 2003, Lubinsky et al., 2009) performance was nonetheless close to perfect, regardless of depression status (*M*=97% correct), which aligns with the intention of EL-SG and succeeded in replicating the memory benefits observed in previous research.

Self-Generation Immediate Free Recall

Self-generation produced better performance than both the EL and EF learning conditions at free recall, which is consistent with literature showing the benefits of self-generation learning methods over trial-and-error learning (Tailby & Hasalm, 2009, Laffan et al., 2010). The additive benefits of self-generation to errorless learning lends support to the theory that elaboration, and not just error elimination, during encoding helps facilitate recall (Lubinsky et al., 2009 (study 2), Laffan et al., 2010).

In addition to confirming the added benefit of self-generation to EL learning procedures, the present study showed that EL-SG can help improve free recall, which is a memory task that demands more from executive functions. Research in self-generation procedures is relatively new, with only a handful of studies using free recall as an outcome measure (Guild & Anderson, 2012, Hasalm et al., 2017, Lubinsky et al., 2009), and only two studies showing benefits of EL-SG on free recalled tasks (Hasalm et al., 2012; Hasalm et al., 2012), which were conducted with children. Notably, the current study observed free recall benefits using unrelated information, which places a greater burden on executive functioning systems as relationships between words are not readily apparent and require greater effort for elaboration and organization.

Self-generation may help guide organization or elaboration of unrelated information by eliciting a larger semantic network that is more easily accessed and activated during retrieval (Tailby & Hasalm, 2003). The EL-SG cue gave participants imagery-rich descriptions of target words which activates semantic networks with less effort (Craike & Lockhart, 1972). In contrast, participants in the standard EL or EF condition did not see any semantic information along with the word and would have had to generate mnemonic strategies spontaneously or using effortful control. Indeed, one participant described spontaneously adopting the use of a strategy in the qualitative portion of this study. Thus, self-generation may help to bypass executive deficits by helping participants utilize elaborative strategies with minimal effort (e.g., Hasalm et al., 2017). Importantly, this effect occurred in a sample with symptoms of depression, indicating that this elaboration strategy may be useful in bypassing the difficulties with spontaneous elaboration and organization seen in depressed populations (Lamar et al., 2010).

In support of the notion that EL-SG works through greater elaboration, this study, combined with other literature, suggests that the content of the self-generation could impact the strength of free recall. Lubinsky et al., (2009) limited the cues to the stem ("BAN") and a short cue, "it is related to fruit" and found no free recall benefits. In contrast, the current study used semantically rich cues, with a lot of information included and observed better free recall performance. Similarly, Haslam et al., (2012) observed free recall benefits for self-generation over errorful learning using long, semantically rich cues that the current study mimicked (e.g., "it begins with CH, it's a piece of furniture that you usually sit on and it has four legs"). Together, this could indicate that the length of the self-generation cue impacts free recall performance. While the present study does not address cue-length, it may be that in clinical situations self-generation procedures should use highly elaborative cues to help facilitate performance.

Finally, like EL immediate free recall, the finding that EL-SG benefited free recall in a healthy population indicates that EL-SG benefits individuals who have relatively intact explicit memory and executive functions. This is an interesting finding, as errorless learning was originally purported to only benefit people with severely impaired explicit memory systems (Baddeley & Wilson, 1993). Thus, EL-SG could be extended to populations with intact memory systems that wish to improve their mnemonic abilities.

In addition, the advantage of EL-SG observed in the current study contributes to a small body of literature showing that EL-SG is beneficial for individuals with mild to moderate cognitive deficits, such as individuals with depression (Tailby & Haslam, 2003). While depressed participants performed similarly to controls in this study, research shows that on standardized tests of memory, depressed patients typically show deficits (e.g., Beblo et al., 2020. McCall & Dunn, 2003 Jaeger et al., 2006) and may therefore benefit from this intervention. In contrast, EL-SG has been shown to be detrimental for individuals with more severe memory impairments who appear to benefit most from standard errorless learning (Hasalm et al., 2012, Lubinsky et al., 2009).

Self-Generation Cued Recall

Errorless learning plus self-generation produced more durable memory representations for cued recall, as compared to both errorful learning and standard errorless learning. This is consistent with a small body of literature showing cued recall benefits for EL-SG (Lubinsky et al., 2009, Laffan et al., 2010, Tailby and Hasalm, 2003) with cued recall more reliably producing a difference as compared to free recall (Lubinsky et al., 2009) in controls and with participants with moderate to severe symptoms of depression.

Additionally, like the idea explored above, the benefits of EL-SG for cued recall supports the importance of facilitating good attention during encoding. For the EL-SG condition, participants were shown the stem and then given a semantically rich description. This procedure would have forced participants to pay attention to the stem as the description was sometimes imprecise enough to elicit other answers. For instance, for the cue, “metal coverings formerly worn by soldiers or warriors to protect the body in battle” words like “mail” or “sword” may come to mind without the stem “AR” to guide the participant to the target word “armor.” As a result, the EL-SG condition may have outperformed the EL condition for cued recall because the procedure forced participants to appropriately attend to the stem. Again, this is a more active approach to learning that facilitates recall because participants are engaged and experience a learning environment that mimics the demands of retrieval (Craik & Lockhart, 1975).

Interestingly, the impact of EL-SG on cued recall may be restricted to samples that have mild impairments. For instance, using a procedure very similar to this present study, but in a population with severe memory impairment, Hasalm et al., (2012) observed that self-generation did not outperform standard errorless learning procedures for cued recall. In contrast, later studies performed by this same research group with patients that had more mild memory impairments observed cued recall benefits for EL-SG over and above EL learning (Hasalm et al., 2017). This suggests that self-generation could be more cognitively burdensome than standard errorless learning which aids those who have generally intact cognitive capacity but hurts those who are more limited in their ability to interact with the cues.

Indeed, samples that find EL-SG benefits in severely impaired populations tend to use self-generation cues that are much more accessible than those used in the present study. For instance, in a sample of patients with probable or possible Alzheimer’s Disease, Laffan et al., (2010) had participants match famous faces with their names. However, in the self-generation condition they gave clues that provided substantial structure (e.g., “Bill Clin---) along with visually rich pictures, which may be necessary for self-generation to aid individuals with more severe deficits. The current study cannot comment on the differences in EL-SG efficacy for individuals with mild versus severe impairments as the present sample had relatively intact cognitive abilities. However, these findings are consistent with research showing that semantically rich cues benefit cued recall for populations with minimal to mild impairment.

Self-Generation Delayed Recall

Interestingly, as compared to EL learning, self-generation research tends to include more measures of delayed recall. Some researchers have observed no additive benefit of EL-SG (as compared to EL) at delayed recall (Hasalm et al., 2012). However, others have observed that EL-SG creates more durable memory traces than other forms of learning (Laffan et al., 2010, Lubinsky et al., 2009, Tailby & Hasalm, 2003), although all these studies used delayed cued recall as an outcome measure rather than free recall. The current study observed no effects of EL-SG on delayed recall, likely due to the recency effects described above. Indeed, given the extent of the recency effects in this study "delayed" recall may be a misnomer.

Depression and Learning Conditions

The third hypothesis proposed that there would be interaction effects for depression status, in which participants with symptoms of depression benefited most from EL-SG or suffered more under EF procedures, as compared to the control group. Unfortunately, this study did not observe memory differences between the two groups which eliminated the ability to see proposed interaction effects between depression status and learning condition.

Implications for Depressed Populations

While there were no main effects for depression status, the finding that EL and EL-SG equally benefited healthy and depressed populations indicates that these strategies could help offset the verbal memory deficits observed in depression (Austin et al., 2001; Jaeger et al., 2006). Depressed populations consistently show deficits in executive functions (Snyder et al., 2013), which is believed to drive verbal memory deficits. The current study offers support for the notion that EL and EL-SG help bypass executive functioning difficulties by eliminating the need to inhibit errors, as both errorless conditions outperformed the EF condition. Moreover, both errorless conditions facilitated free recall, which is a highly executive task. This suggests that reducing the burden on error-monitoring systems through error elimination, makes it easier to effortfully retrieve learned information.

Additionally, EL-SG appears to have an additive benefit for the depressed and healthy groups by helping them elaborate on material during encoding, which likely reduced the demands on executive functioning to spontaneously perform this task (Hertel 2000). This is an important finding, as individuals with depression tend to struggle most on verbal memory tasks that require strategic organization and elaboration, such as lists of unrelated words (Lamar et al., 2010, Elderkin-Thompson et al., 2007). Additionally, the added benefit of EL-SG for the depressed group is consistent with literature showing that people with depression perform normally on tasks that facilitate elaborative encoding (Hertel 1994, McFarland et al., 2017).

Clinically, the findings of the present study suggests that individuals with depression would benefit from learning information in a manner that helps them elaborate on the material to be learned. In particular, EL procedures could enhance the efficacy of psychotherapies by helping individuals learn and remember skills taught in session. For instance, errorless learning may help depressed individuals learn the TIPP skills (i.e., Temperature, Intense Exercise, Paced Breathing, Progressive Muscle Relaxation) from Dialectical Behavior Therapy as the acronym can be difficult to remember as it does not provide rich semantic information. Indeed, depressed individuals with memory impairments respond poorly to commonly used psychotherapies (e.g., CBT) (Kundermann et al., 2015), suggesting that supplementing psychotherapies with cognitive rehabilitation techniques could enhance the efficacy of existing treatment modalities. Along these same lines, depressed patients may also benefit from their therapist facilitating increased rehearsal and connection of material to their prior learning. Moreover, in group settings, individuals with depression may not benefit from being forced to guess answers to the assigned homework assignment, as this could set up errors that compete with the correct answers. Instead, they may benefit from being given clues until they can arrive at the correct answers themselves.

Limitations for Depression Status

Examination of means for the learning tasks indicates that the study was restricted by the similarity in cognitive abilities of the depressed and healthy group. There are several reasons this study may not have observed proposed interaction effects.

First, it is possible that the task used for the present study was unable to capture the memory impairments in depression because *symptoms* of depression was used as the primary inclusion criteria, rather than diagnosis of depression, which is a more reliable indicator of depression status and severity. As a result, the depressed sample may not be an accurate representation of the memory abilities of people with depression, as participants could have had subthreshold depression, or other diagnoses masquerading as depression as measured by the PHQ-8 (e.g., PTSD, anxiety, health problems). Indeed, most studies examining deficits in depression tend to use depression diagnosis rather than a screening measure such as the PHQ-8 which may be needed to observe the subtle memory deficits in depression (e.g., Airaksinenen, 2006, Conradi et al., 2011, East-Richard et al., 2019). Moreover, even within diagnosed populations there can be some variability in observations of memory impairment because depression deficits are subtle and subject to variations such as speed of the task or lack of power (see McDermott & Ebeier, 2009 for a meta-analysis).

Secondly, the motivations of MTurk workers to qualify for the study may have impacted the composition of the two groups. MTurk workers may know that researchers tend to screen depressed participants *out* of research studies, rather than wanting to recruit participants with depression. Consequently, there may be some MTurk workers that were motivated to underrepresent their symptoms of depression to qualify for the study, that were then analyzed as “non-depressed” and introduced error into the analyses. Conversely, participants may have assumed that the study was recruiting depressed participants as the PHQ-8 was included in the screening tools. As a result, non-depressed participants may have endorsed high rates of depressive symptomology to qualify for the study. However, these explanations seem less likely because the prevalence rate of depression in the current sample was very similar to other prevalence rates observed in other MTurk studies. For instance, Ophir (2019) screened over 2,000 MTurk workers and found that 18.5% met the same PHQ-8 cut-off used in the present study, which is close to the prevalence rate of depression in the present study (19.7%).

Thirdly, the task itself may have lacked the difficulty needed to observe the subtle memory deficits in depression. While this study attempted to create word lists that were difficult to learn (i.e., low accessibility indices), this is the first time the lists have been used in a sample of participant and may have been easier to learn than anticipated because of the study design. For instance, this study told participants that the target words were 5-6 letter words and were nouns, which restricted possible answers and may have increased the ease with which target words were produced and remembered. Indeed, 77% of the sample guessed one or more of the target words on the first trial of errorful learning, which indicates that certain stems easily elicited the target word. Anecdotally, the stem “SK” appeared to produce high rates of participants immediately producing the word “skate.” However, while some words were guessed on the first try in EF learning, it is important to note that correct answers on the first trial were relatively rare overall (M=1.1, SD=1.0), with 73% of the sample making 14 out of 16 possible errors on trial 1 of errorful learning. Thus, the lists largely functioned as intended as they produced many errors for both groups and resulted in worse recall performance as compared to the two errorless conditions.

In addition, memory performances ranged from 0 to 16 words recalled, which indicates that the task was too easy for some participants as they reached the ceiling (16). However, the number of words retrieved for free, cued, and delayed recall ranged from about 6 to 13 words on average which indicates that the attempts to make this task more difficult than prior research was effective. For instance, Tailby & Hasalm, (2003) used a list of 12 words, which would have resulted in ceiling effects for the present sample. Moreover, examination of standard deviations shows that recall performances one standard deviation above the mean were still below the ceiling of 16 words for all recall tasks. This offers compelling evidence that the task was sufficiently difficult for most of the sample.

Finally, the lack of control introduced by having participants complete the experiment outside of the lab may have obscured results to the extent that the healthy and control groups looked similar. Indeed, the presence of “unacceptable” errors speaks to some of the problems that may occur because this study was conducted in uncontrolled environment. Moreover, participants could have written down the words despite instructions not to do so, as there was no way to monitor this virtually. However, this argument is less convincing as the expected differences were generally observed between EF, EL and EL-SG learning, which replicates previous research and speaks to the ability of online research to produce quality experimental results.

Learning Preference

The fourth hypothesis proposed that there would be a main effect for preference, in which both groups preferred errorless learning plus self-generation. Using rank orders, and Likert-scale preference ratings this study showed that errorless learning plus self-generation was far more preferred than the other two learning methods. This is a novel finding, as no other study has included measurements of likeability or preference. While no other research has measured preference, several researchers have commented that participants seem to enjoy the EL-SG condition more than the other learning methods. (Hasalm et al., 2012, Laffan et al., 2010). Indeed, Hasalm et al., (2017) commented that participants seemed to respond more quickly and confidently for information learned with self-generation procedures. The current study extends these observations by providing empirical evidence that participants prefer EL-SG over and above other learning methods. Indeed, examination of means shows that the mean likeability rating for EL-SG was close to the ceiling for "I really liked this way of learning" (*M*=6.05), whereas EL (*M*=4.30) and EF learning (*M*=3.34) were both closer to neutral.

Preference for EL-SG across groups could suggest an additional mechanism through which elaboration procedures benefit learning, although this was not examined in the present study. Self-generation may benefit people with depression, as well as healthy individuals, by increasing interest and attention to the information to be learned, which is a crucial component of memory (e.g., Zawadzka & Hanczakowski, 2018 for EL paradigm). Moreover, research suggests that increasing the relevance of material to the learner impacts recall performances (Wilson, 2005). Notably, both depressed and non-depressed participants rated EL-SG as their preferred learning method, perhaps because it was interactive and interesting, and required less effortful control to maintain engagement with the material.

It was also interesting to note that some participants ranked EF learning over and above EL learning, with 24.8% of the sample ranking EL learning as least liked. The primary difference between these conditions is that EF learning is more active, whereas EL learning is passive and may feel boring for individuals who have generally intact explicit and executive abilities, such as the present sample. In contrast to EL rankings, only 1.8% of the sample rated EL-SG as least liked, which speaks to the general likability of this learning method. Future research could examine whether the patterns for preference differ depending upon severity of cognitive impairments, and whether degree to which participants enjoy the task impacts memory performance or effort.

Qualitative Feedback

Overall, qualitive feedback included positive remarks about the study being enjoyable and running smoothly, which aligns with my own experience of the quality of participant data and research showing good outcomes for MTurk behavioral science research (Horton et al., 2011). Comments indicated that some participants had a sense of which learning method worked best for them and could even recall spontaneous strategies they used throughout the study. This presents an interesting area for future research, as it could be possible to ask participants at the end of the study whether they spontaneously adopted a strategy and examine wither that aligns with the different hypotheses for errorless learning.

Limitations

Methodological Limitations

Similar Memory Performances.

The largest limitation of this study is the failure to observe a main effect for depression status on memory performance. At the very least, the errorful learning condition should have shown better performances for the non-depressed group, as compared to the depressed group. Research with psychiatric populations have found interaction effects for EL conditions in clinical samples but used DSM diagnostic criteria for inclusion in the study (Pope & Kern, 2009). The current study used the PHQ-8 to identify depressed individuals, which is a screening tool and cannot be used to diagnose Major Depressive Disorder, which can only be done through an interview with a trained professional that confirms DSM criteria and rules-out differential diagnoses. Future studies interested in this question should consider finding a clinically depressed patient population that meets diagnostic criteria for MDD to observe any interaction effects and better understand the mechanism through which errorless learning functions to benefit recall.

Lack of control over times.

This study attempted to control for time by displaying the target word for the same length of time and equating the length of feedback. That being said, one of the potential limits of this study were the time differences for the three learning conditions. While statistical analyses did not confirm that these differences were significant, examination of means shows a noticeable difference between the minutes spent learning in EF (*M*=7.39, SD=1.83), EL-SG learning (*M*=6.38, SD=1.67) and EL learning (*M*=5.08, SD=.714). Time spent studying is known to predict retention of information and may have impacted performance. Thus, it is possible that EL-SG outperformed EL simply because participants spent more time in the self-generation condition than they did for standard errorless learning. However, despite taking a shorter amount of time than EF learning, the EL-SG nonetheless produced better recall, which calls this explanation into question.

One of the dilemmas in examining the impact of study time is that it is difficult to tell how long each condition spent encoding the actual target word, as opposed to completing other task demands. For instance, for the EL condition they merely read the target word, which explains why it was the quickest condition, whereas in the other two conditions participants needed to generate an error or read a semantically rich cue. These extra demands take more time but is not the same as seeing and encoding the target word. Given the design, it’s also possible that participants who were motivated to do well typed in the correct answer and waited several seconds to better encode the word before hitting “enter.” As a result, it is difficult to know whether the groups truly differed in how long they spent interacting with the target word, without finer grained analyses than was conducted in the present study.

Importantly, studies that have equated the learning times for EL-SG and EL learning still observe an additive benefit for the self-generation procedures (Guild & Anderson, 2012) which argues against the idea that the differences in recall for the present study are due solely to time differences. Moreover, it is important to consider the potential drawbacks of equating the three conditions. For instance, if the EL condition is prolonged participants may feel greater boredom and disengage from the task, which could then drive results as attention is crucial for learning (Clare & Jones, 2008).

The range in study time for the three conditions generates questions about the mechanism through which EL-SG confers benefits. Additional research along the lines of Guild & Anderson (2012), which equated each condition, could help answer that question. Thus, the current study is unable to comment on the impact of length of time spent in each condition without further analyses.

Cued & Delayed Recall procedures

As discussed above, cued recall in the EL condition may have inadvertently reduced the level of attention participants had to the stem, which should be addressed in future research to better equate the conditions. Thus, it is possible that the difference observed between EL and EL-SG for cued recall, but not free recall, is due to this methodological problem.

Additionally, there were some methodological limitations with delayed recall that could be addressed in future studies. For instance, increasing the time for delayed free recall would be needed to eliminate recency and time effects and observe the durability of these learning methods over time which would contribute to generalizability. It may work best to isolate each learning condition so that they do not occur one after the other. Alternatively, a between-subjects design could be used to test the differences between the three learning conditions which would result in a standard time between the end of the learning trials and the beginning of delayed recall.

Unacceptable Errors & Correct Guesses

The study produced "unacceptable" errors that did not appear to overly disrupt results but could be reduced in future iterations. The mechanism of unacceptable errors is unclear, and could include poor effort, inattention, lack of control in environment, input errors, or technological problems (e.g., participant accidentally hitting the "next" button early before they finished typing). Individual examination of extreme cases did not demonstrate consistently poor performance across the memory task for those that made multiple unacceptable errors. However, future research could improve on the study design to eliminate unacceptable errors. For instance, the paradigm could be set up so that participants must type in a certain number of characters to proceed, as many of the unacceptable errors were simply the stem (e.g., "ca") or the word "skip."

Additionally, nearly half of the sample guessed at least one word on trial 1 of errorful learning, which facilitated recall. In-person research typically uses an alternative target word in these cases, which may produce more robust interference effects. Despite correct guesses in the EF condition, this condition still resulted in poorer performance than the EL conditions, which suggests there were enough errors to produce similar effects to prior research.

Generalizability

One of the common criticisms of EL learning is that it lacks generalizability for real-world tasks, as errorless learning is most beneficial for information that is unrelated, and the cue and retention are perfectly matched (i.e., cued recall); (Squires et al., 1997). The current study somewhat challenges this idea by showing that EL and EL-SG also benefited free recall, which expands the applicability of errorless learning beyond cued recall tasks. However, the current study still used unrelated stimuli, which is relatively rare in everyday life. For instance, a grocery list can seem semantically unrelated at first, but has clear categories that help with memory and may not benefit from errorless procedures (e.g., fruits, meats, frozen section). Further research is required to clarify which tasks benefit most from the use of errorless learning procedures.

Additionally, while the learning condition showed significant main effects, the differences between groups may not be clinically meaningful, as EL-SG condition resulted in just 1-2 words more than the other conditions. Whether these strategies could help people with mild impairments experience tangible changes in school or occupational functioning remains to be seen.

Future Directions

More research needs to be done to determine which interventions work best for people with MDD and can feasibly be applied to every-day problems that arise. One principle emphasized in this current study is the need to develop memory interventions that support executive functioning difficulties, as this is the area most impaired in MDD (Snyder 2013). Errorless learning procedures could uniquely benefit people with depression by eliminating the need to monitor and inhibit errors during encoding and retrieval. Moreover, self-generation helps facilitate elaboration on material, which is typically an effortful process and more challenging for people with depression. In addition to more research with errorless procedures, other kinds of elaboration procedures could be explored, such as intentionally linking information with previously learned material, or intentionally creating associations between the words.

While EL benefits have been observed in highly controlled environments such as experiments and rehabilitation centers there are few studies that extend this principle to real-world environments. For instance, it would be interesting to teach errorless learning principles to depressed individuals with occupational difficulties and observe whether it helps alleviate frustration and stress in the work environment. These kinds of studies would lack control but would help establish the ecological validity of errorless learning as a technique useful for people with mild impairments.

Similarly, psychoeducation is another avenue that could be beneficial for depressed populations with mild impairments, as they generally retain the explicit memory abilities needed to learn and retrieve educational material. Greater awareness of cognitive problems in depression, and their origin (i.e., biological changes, executive dysfunction, sleep deprivation) could help reduce fear about cognitive difficulties and help individuals actively change their own environments. Moreover, psychoeducation could help reduce the internalized toll that cognitive problems have by reducing negative self-evaluations that one is “stupid” or “not trying hard enough” while also empowering patients to actively compensate for their difficulties. Importantly, medical and mental health providers may also require greater psychoeducation about cognitive problems in depression, as people often misattribute memory impairments in younger, depressed adults to other disorders (e.g., Learning Disability, Traumatic Brain Injury, Attention Deficit Disorder), or misperceive impairments as dementia in the case of older adults with depression (aptly named “pseudodementia”). As a result, patients may receive inappropriate treatments that do not accurately reflect the etiology of their memory complaints and could create additional problems.

In addition to errorless learning methods, other cognitive rehabilitation methods may prove to be beneficial for individuals with depression, such as teaching people with depression to learn information in small chunks to limit the burden on organizational strategies or use external assistive devices. Researchers have observed the positive benefits of these interventions in other patient populations, but minimal research has applied these principles in depressed populations (McIntyre et al., 2013).

At a methodological level, errorless learning paradigms could better control for time spent studying, as well as the impact of other possible mechanisms for the errorless learning advantage. For instance, the present study found that participants overwhelmingly preferred self-generation procedures, which may have resulted in greater engagement and effort on the task. Notably, increasing interest would help facilitate executive functioning by minimizing the need to exert effortful control over a task that one finds uninteresting. Additional research is needed to explore that mechanism. This study also raised questions about the importance of cue length in facilitating recall for the self-generation condition. Studies could address these questions by comparing different approaches to self-generation procedures (e.g., short cues vs. long cues, simply giving categories, cues with or without cultural references etc.).

Conclusion

The present study investigated the benefits of errorless learning procedures in a sample with minimal to severe symptoms of depression and found that the elimination of errors during the encoding process equally benefits both groups for immediate free and cued recall tasks. This replicates and extends prior research by showing that errorless learning benefits a depressed population, who often present with mild verbal memory deficits (Goodall et al., 2018, East-Richards et al., 2019, Vicent-gil et al., 2018). In addition, this study contributes to a growing literature base showing that self-generation procedures, in which participants arrive at the answer using semantically rich clues, has an additive benefit on the effectiveness of errorless learning.

A novel finding from the present study is that participants overwhelmingly prefer self-generation procedures over and above typical trial-and-error procedures as well as standard errorless learning procedures. Interestingly, participants sometimes preferred EF learning over EL learning, which may reflect the higher level of engagement required for the EF procedures. This warrants further research to determine if it is a possible mechanism for the benefits of errorless learning overall.

In addition, this study observed a pattern of data that was consistent with the executive functioning hypothesis for errorless learning. An inverse relationship was observed between number of errors generated during trial-and-error learning, and immediate and cued recall, suggesting that there is a dose-response relationship between errors and retention. Free recall performance was also enhanced by EL learning procedures. Combined, these findings offer support for the notion that error elimination helps reduce the burden on executive functions to monitor for and inhibit errors. Finally, self-generation benefits may be attributable to deeper processing, which takes more effortful, executive control in the EF and EL learning procedures as those conditions did not include any semantic information along with the target word.

Overall, the present study offers a first look at the potential benefits of errorless learning in a sample with symptoms of moderate to severe depression. Future research should continue to explore rehabilitation techniques that can address the verbal memory deficits observed in this psychiatric population. Addressing cognitive impairments is a novel way to supplement and improve on existing treatments aimed at enhancing quality of life and cultivating mastery in people with depression.

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Appendix A

Screener Items

The following items were presented in the screener to qualify for the study. Items are presented in the order that they were shown to participants.

A1: Attention check items

1.) I am a human being.
Maybe Yes No Cannot say for sure Definitely not I don't know Tigers

2.) Thanksgiving is probably best described as:
An Animal A rock star A kind of tree A holiday Bakery Store Maybe No Yes

3.) An oak is probably best described as:
Yes No A tree A human being A lion Weather A seismic anomaly Maybe I don't know

A2: Demographic Questions

1. What is your age in years?
   [options 18-100+]

2. How would you describe your gender?
   Male
   Female
   Transgender male
   Transgender female
   Non-binary
   Other______

3. Is English your first language?
   Yes No

4. What is the highest level of education you have completed?
   Less than high school
   Some high school
   Highschool diploma or equivalent
   Associates degree
   1 year of college
   2 years of college
   3 years of college
   Graduated from college
   Some graduate school
   Master's degree
   Ph.D. or higher

Other_____

A3: Health Screening Questions

Have you been diagnosed with the following conditions? If you are not sure please answer “no.”

1. Asthma
2. Anemia/blood disease
3. High cholesterol
4. Heart attack/heart disease
5. Diabetes
6. Anxiety
7. Depression
8. Attention deficit disorder (ADD) or Attention deficit hyperactivity disorder (ADHD)
9. Mild brain injury (concussion) (heady injury resulting in loss of consciousness for 0-30 minutes).
10. Moderate or severe brain injury (head injury resulting in loss of consciousness greater than 30 minutes, usually requires hospitalization).
11. Thyroid Disease
12. Arthritis
13. Obesity
14. Migraines
15. Bells Palsy
16. Cystic Fibrosis

A4: Patient Health Questionnaire 8-Item (PHQ-8)

Over the last 2 weeks how often have you been bothered by any of the following problems?
0=not at all
1=several days
2=more than half the days
3=nearly every day

1. Little interest or pleasure in doing things
2. Feeling down, depressed or hopeless
3. Trouble falling or staying asleep, or sleeping too much
4. Feeling tired or having little energy
5. Poor appetite or overeating
6. Feeling bad about yourself—or that you are a failure or have let yourself or your family down
7. Trouble concentrating on things, such as reading the newspaper or watching television
8. Moving or speaking so slowly that other people could have noticed? Or so fidgety or restless that you have been moving a lot more than usual?

Appendix B
Learning Conditions

B1. Errorful Learning Condition

[Note: the 16 target words and experimenter errors were taken from one of the 3 lists in Appendix C]

Screen 1 Instructions

You may stay on this screen for 3 minutes if you would like a break! After 3 minutes the computer will automatically advance to the next screen.

Instructions

For this list of 16 words, you will be given a two-letter stem such as "SN" and will guess the word that could complete the stem. You will type your guess into the computer and hit the "enter" key and will be told if your guess was correct. If your guess is incorrect you will be told the correct answer. Try to remember the correct answer.

- The words will *not* be proper nouns, like the name of a person or a place
- You will have 25 seconds to make a guess and will have 2 chances to learn each word.
- At the end, you will be asked to type as many of these words as you can remember, in any order.

(Next screen)

I am thinking of a word that begins with *(2 letter stem such as BR)*

(Next screen)

Please type your guess below
[entry box]

(screen if incorrect)

That’s incorrect
The word is *(target word)*
Please type the correct answer below
[entry box]
(green check-mark when correct)

(Next screen if correct)

Correct! The word is *(target word)*
The word is not *(experimenter error here.).*

(*After all 16 words are learned the first time)*

Well done! You will now have a second chance to learn those same 16 words. Try to remember them.
(The above procedure is repeated for those same 16 words)

(screen shown after 16 words are learned 2 times)

Great job! Now we'll see how many you can remember.

[recall instructions shown]

B2: Errorless Learning Condition

[Note: the 16 target words were taken from one of the lists in Appendix C.].

Screen 1 Instructions

You may stay on this screen for 3 minutes if you would like a break! After 3 minutes the computer will automatically advance to the next screen.

Instructions

- For this list of 16 words, you will be shown words one at a time. Please type the word you are given and press the "enter" key. Try to remember the word you are given.
- You will have 25 seconds to type the answer and two chances to learn each word.
- At the end, you will be asked to type as many words as you can remember, in any order.

(Next screen)

I am thinking of a word that begins with *(2 letter stem such as BR)* and this word is *(target word shown such as BREAD)*

(Next screen)
Please type that word below
[entry box]

(Screen if incorrect)
You answered (*participants answer here),* which is incorrect
The word is *(target word)*
Please type the correct answer below
[entry box]
(green check-mark shown when correct)

(Screen if correct)
Correct!

(*After all 16 words are learned the first time)*

Well done! You will now have a second chance to learn those same 16 words. Try to remember them.

(The above procedure is repeated for those same 16 words)

(Screen shown after 16 words are learned 2 times)

Great job! Now we'll see how many you can remember.

B3: Errorless Learning- Self-Generation Learning Condition

(*Screen1 instructions)*

You may stay on this screen for 3 minutes if you would like a break! After 3 minutes the computer will automatically advance to the next screen.

Instructions

- For this list of 16 words, you will be shown clues to help you guess the words. You will then type your guess into the computer and hit the "enter" key and will be told if your guess was correct. Try to remember the correct answer.
- You will have 25 seconds to make your best guess and two chances to learn each word.
- At the end, you will be asked to type as many words as you can remember, in any order.

Good luck!

(Next screen)

I am thinking of a word that begins with *(2 letter stem such as AR)* and this word describes *(descriptive clues in Appendix D)*

(Next screen)
Please type that word below
[entry box]

(Screen if incorrect)
You answered (*participants answer here),* which is incorrect
The word is *(target word)*
Please type the correct answer below
[entry box]
(green check-mark shown when correct)

(Screen if correct)
Correct! The word is *(target word)*

(*After all 16 words are learned the first time)*

Well done! You will now have a second chance to learn those same 16 words. Try to remember them.

(The above procedure is repeated for those same 16 words)

(screen shown after 16 words are learned 2 times)

Great job! Now we'll see how many you can remember.

[recall instructions shown]

Appendix C

Target lists with alternate experimenter errors

	List A		**List B**		**List C**	
	Target	*EE*	*Target*	*EE*	*Target*	*EE*
1	Armor	Arrow	Attic	Atlas	Ankle	Angel
2	Clown	Closet	Bench	Beard	Bacon	Basket
3	Diary	Ditch	Boxer	Bonus	Eagle	Easter
4	Drawer	Dryer	Cabin	Castle	Frown	Frost
5	Fence	Fever	Creek	Crown	Groom	Gravel
6	Garage	Garlic	Dollar	Dough	Napkin	Nails
7	Hanger	Handle	Fairy	Fabric	Opera	Option
8	Ladder	Label	Flute	Flame	Prince	Prize
9	Motel	Motor	Glove	Glory	Puddle	Pupil
10	Pasta	Paddle	Helmet	Helper	Quilt	Quart
11	Saddle	Safari	Lemon	Leaves	Rubber	Runner
12	Scarf	Screw	Maple	Maker	Statue	Stove
13	Sheep	Shave	Robot	Rodeo	Sword	Switch
14	Subway	Suburb	Skate	Skirt	Towel	Tongue
15	Thumb	Thorn	Sleeve	Slope	Tulip	Turnip
16	Violet	Viola	Soccer	socks	Wallet	Waiter

Note. EE=Experimenter Error

Appendix D

Descriptive Clues for Self-Generation Condition

Table D1: List A Self-Generation Cues

Target	Descriptive Clue
Armor	I'm thinking of a 5-letter word that begins with AR and this word describes metal coverings formerly worn by soldiers or warriors to protect the body in battle
Clown	I am thinking of a 5-letter word that begins with CL and describes a comic performer, as in a circus, who wears outlandish costume and makeup and entertains by juggling or tumbling
Diary	I am thinking of a 5-letter word that begins with DI and describes a journal in which one writes down secrets or daily events, which sometimes has a lock to keep people from reading the contents
Drawer	I am thinking of a 6-letter word that begins with DR and describes a box-shaped storage compartment that is made to slide horizontally in and out of a desk, chest, or other piece of furniture
Fence	I am thinking of a 5-letter word that begins with FE and describes a barrier, railing or other upright structure, typically of wood and wire, enclosing an area of ground to mark a boundary, control access or prevent escape
Garage	I am thinking of a 6-letter word that begins with GA and this word describes a part of a house in which the car is parked
Hanger	I am thinking of a 6-letter word that begins with HA and describes a shoulder-shaped frame with a hook at the top, usually of wire, wood or plastic on which garments are hung and placed in a closet
Ladder	I am thinking of a 6-letter word that begins with LA and describes a structure consisting of a series of steps between two upright lengths of wood, often used for climbing to high places on construction sites
Motel	I am thinking of a 5-letter word that begins with MO and this word describes a kind of roadside hotel designed primarily for motorists, with rooms arranged in a low building with parking directly outside
Pasta	I am thinking of a 5-letter word that begins with PA and describes a kind of food that originated in Italy, and is made from dough and stamped into various shapes and typically cooked in boiling water, such as spaghetti
Saddle	I am thinking of a 6-letter word that begins with SA and describes a seat for a rider on the back of a horse or other animal, often made of leather
Scarf	I am thinking of a 5-letter word that begins with SC and describes clothing that is made out of a length or square fabric worn around the neck or head
Sheep	I am thinking of a 5-letter word that begins with SH and describes a domesticated animal with a thick wooly coat which is sheared to make clothing

Subway	I am thinking of a 6-letter word that begins with SU and describes a method of transportation in which an electric train travels through underground tunnels, such as found in major cities like New York City, or Beijing.
Thumb	I am thinking of a 5-letter word that begins with TH and describes a finger on the human hand that is short, thick, opposable, and helps humans grab things
Violet	I am thinking of a 6-letter word that begins with VI and describes a kind of flower that often has purple or blue petals, also used to describe a shade of purple

Table D2: List B Self-Generation Cues

Target	Descriptive Clue
Attic	I am thinking of a 5-letter word that begins with AT and describes a space or room below the roof of the house, which is often large enough to walk in and used to store things like Christmas decorations
Bench	I am thinking of a 5-letter word that begins with BE and describes a long seat for several people, typically made of wood and often found in public parks
Boxer	I am thinking of a 5-letter word that begins with BO and describes a person who fights other people for sport or money, inside a roped square ring with padded hand protection
Cabin	I am thinking of a 5-letter word that begins with CA and describes a kind of building that is often built in the wild or remote areas and made of logs
Creek	I am thinking of a 5-letter word that begins with CR and describes a stream, brook, or minor tributary of a river
Dollar	I am thinking of a 6-letter word that begins with DO and describes the basic monetary unit of the United States which is made of paper and green in color
Fairy	I am thinking of a 5-letter word that begins with FA and describes a small imaginary being in human form that has magical powers, especially a female one such as Tinker Bell from the popular story Peter Pan
Flute	I am thinking of a 5-letter word that begins with FL and describes a wind instrument made from a tube with holes along it that are stopped by the fingers, held vertically or horizontally so that the players breath makes music
Glove	I am thinking of a 5-letter word that begins with GL and this word describes a kind of clothing that is worn on the hand for protection against cold or direct and typically has separate parts for each finger and the thumb
Helmet	I am thinking of a 6-letter word that begins with HE and describes a hard or padded protected hat to protect the head, with various types worn by bicyclists, soldiers, police officers, football players, and motorcyclists
Lemon	I am thinking of a 5-letter word that begins with LE and describes a yellow, oval citrus fruit with thick skin and acidic juice

Maple	I am thinking of a 5-letter word that begins with MA and describes a kind of tree with colorful autumn leaves, grown for its syrupy sap
Robot	I am thinking of a 5-letter word that begins with RO and describes a kind of machine resembling a human being and is able to replicate certain human movements and functions automatically
Skate	I am thinking of a 5-letter word that begins with SK and describes an object that goes on the foot and has wheels on the bottom, or a blade on the bottom for playing hockey on ice
Sleeve	I am thinking of a 6-letter word that begins with SL and describes the part of a shirt or a sweater that wholly or partly covers the arm
Soccer	I am thinking of a 6-letter word that begins with SO and describes a game played by two teams of 11 players with a ground ball that may not be touched by the hands, with the object to score goals

Table D3: List C Self-Generation Cues

Target	Descriptive Clue
Ankle	I am thinking of a 5-letter word that begins with AN and describes a body part that is a joint and connects the foot with the leg
Bacon	I am thinking of a 5-letter word that begins with BA and this word describes food that is made of pork and is often eaten for breakfast and put on sandwiches
Eagle	I am thinking of a 5-letter word that begins with EA and describes a large bird of prey with a massive, hooked bill and long broad wings, known for its keen sight and powerful soaring flight
Frown	I am thinking of a 5-letter word that begins with FR and describes a facial expression of sadness, disapproval, or concentration, typically by turning down the corners of the mouth
Groom	I am thinking of a 5-letter word that begins with GR and describes a man on his wedding day, just before marrying his bride
Napkin	I am thinking of a 6-letter word that begins with NA and describes a square piece of cloth or paper that is used during a meal to wipe fingers
Opera	I am thinking of a 5-letter word that begins with OP and describes a dramatic kind of musical which is often sung in Italian, has lavish costumes, and features songs with long, loud notes
Prince	I am thinking of a 6-letter word that begins with PR and describes a position of royalty who is often the son of the king
Puddle	I am thinking of a 6-letter word that begins with PU and this word describes a small body of water that can occur after it rains, and that small children like to splash in
Quilt	I am thinking of a 5-letter word that begins with QU and describes a kind of blanket

	that is made of small pieces of cloth sewn together to form a warm bed covering or for a decorative effect
Rubber	I am thinking of a 6-letter word that begins with RU and describes a tough, elastic substance used to make tires for cars
Statue	I am thinking of a 6-letter word that begins with ST and describes a carved or cast figure of a person or animal, especially one that is life-sized or large, such as Lady Liberty in New York City
Sword	I am thinking of a 5-letter word that begins with SW and describes a kind of weapon with a long metal blade and hilt with a hand guard, used for thrusting or striking and is now typically worn as part of ceremonial dress
Towel	I am thinking of a 5-letter word that begins with TO and describes a thick cloth or paper used for drying oneself or wiping things dry.
Tulip	I am thinking of a 5-letter word that begins with TU and describes a kind of flower that has a bulb, has bold colors, and is often seen around Easter time in the USA
Wallet	I am thinking of a 6-letter word that begins with WA and describes an object that holds money or credit cards, and that people carry with them in their purses or pockets

Appendix E

Recall Conditions

E1: Free and cued recall after each learning condition

[*Note. these recall instructions are the same for all 3 learning conditions]*

(free recall)

> One at a time, type in as many words as you can now remember from that list, in any order. Press the "enter" key to submit each word. It's okay to repeat words. When you can't remember any more words press the "I'm done" button
>
> [Entry box below]

(next screen)

> On the next screen you will be shown the first two letters that begin each word you just learned, such as "SN" and you will type the word that completes the stem.

(cued recall)

> Below, please type the **whole word** that goes with the stem. If you're not sure of the answer, make your best guess. If you would like to skip the item type "skip" in the box below.
>
> (*Stem such as BR)* [entry box]

E2 Final Free Recall

[This will be shown after all 3 lists have been learned]

(Screen 1)

Now think back to the FIRST list you learned, at the very beginning. One at a time, type in as many words as you can now remember from that **first** list. Try not to type any words from the other two lists. If you're not sure, type the word anyway. Hit the "enter" key after you type in each word. When you can't remember any more words press the "I'm done" button.

[entry box]

(Screen 2)

Now think back to the SECOND list you learned, the list in the middle. One at a time, type in as many words as you can now remember from that **second** list. Try not to type any words from the other two lists. If you're not sure, type the word anyway. Hit the "enter" key after you type in each word. When you can't remember any more words press the "I'm done" button.

[entry box]

(Screen 3)

Now think back to the LAST list you learned. One at a time, type in as many words as you can now remember from that **last** list. Try not to type any words from the other two lists. If you're not sure, type the word anyway. Hit the "enter" key after you type in each word. When you can't remember any more words press the "I'm done" button.

[entry box]

E3 Recognition stimuli & instructions

Recognition Stimuli:

48 target words: armor, clown, diary, drawer, fence, garage, hanger, ladder, motel, pasta, saddle, scarf, sheep, subway, thumb, violet, attic, bench, boxer, cabin, creek, dollar, fairy, flute, glove, helmet, lemon, maple, robot, skate, sleeve, soccer, ankle, bacon, eagle, frown, groom, napkin, opera, prince, puddle, quilt, rubber, statue, sword, towel, tulip, wallet

48 distractor words: aroma, click, digest, drama, feast, gallon, habit, latin, mower, palace, sailor, screen, shorts, supper, throat, video, attire, belly, booth, cable, craft, donkey, fancy, flavor, globe, hedge, lesson, marble, roses, skunk, sleigh, sonnet, antler, banana, eating, fraud, gravy, nausea, opener, prune, puzzle, quill, rumor, staple, swamp, torch, tuxedo, walnut

Recognition Instructions:

(Screen 1)

On the next screen you will be shown one word at a time. Hit the button "YES" if you were asked to remember that word earlier today and hit the button "NO" if you were not asked to remember that word.

(Screen 2)

Select "YES" if you were asked to learn the word before. Select "NO" if you were not asked to learn the word.

[*Target or distractor word shown-one at a time such as "armor"]*
[yes button] [no button]

Appendix F

Generalized Anxiety Disorder 7-Item (GAD-7)

How often have they been bothered by the following over the past 2 weeks?
Over the last two weeks, how often have you been bothered by the following problems?
0=Not at all
1=Several days
2=More than half the days
3= Nearly every day

1. Feeling nervous, anxious, or on edge
2. Not being able to stop or control worrying
3. Worrying too much about different things
4. Trouble relaxing
5. Being so restless that it is hard to sit still
6. Becoming easily annoyed or irritable
7. Feeling afraid, as if something awful might happen

Appendix G

Learning Preference

Earlier you learned words in three different ways. Please rank your favorite way to learn from 1 to 3. The top choice is your favorite, and the bottom is your least favorite *(Note: these were shown in random order)*

1. Guessing: "I am thinking of a word that begins with BR"
2. Given: "I am thinking of a word that begins with BR and this word is bread"
3. Clues: "I am thinking of a word that begins with BR and this word describes food made of flour, liquid, and yeast which is baked and then sliced to make sandwiches"

How much did you like learning this way?

1. Guessing: "I am thinking of a word that begins with BR"

I did not like this way of learning 1 2 3 4 5 6 7 I really liked this way of learning

2. Given: "I am thinking of a word that begins with BR and the answer is BREAD"

I did not like this way of learning 1 2 3 4 5 6 7 I really liked this way of learning

3. Clues: "I am thinking of a word that begins with BR, and this word describes food made of flour, liquid, and yeast which is baked and then sliced to make sandwiches."

I did not like this way of learning 1 2 3 4 5 6 7 I really liked this way of learning

This question is optional: Do you have any comments or feedback you'd like to share with the investigator?

[response box for comments]

Appendix H

Mental Health Resources

National/International Crises Resources

National Suicide Prevention Lifeline: 1-800-273-8255

- Online Chat and Other Resources: https://suicidepreventionlifeline.org/
- For Deaf and Hard of Hearing (TTY): 1-800-799-4889

Crisis Text Line: Text HOME to 741741
- Online: https://www.crisistextline.org/