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Individual Differences in Long-Term Memory

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The literature on individual differences in long-term memory (LTM) is organized and reviewed. This includes an extensive review of the factor structure of LTM abilities as well as specific individual differences in criterial tasks such as free recall, paired associates recall, and recognition. It is demonstrated that individual differences in LTM abilities are represented by various lower order factors based on criterial tasks as well as by a more general higher-order LTM factor. These individual differences are linked with multiple different constructs including working memory, intelligence, and attention control. Individual differences in forgetting, interference control, false memory, testing effects, general retrieval abilities, and the influence of strategies are also examined. Overall, it is clear that there are substantial and robust individual differences in LTM abilities and that these abilities demonstrate important relations with other cognitive abilities. Future directions and an integration of individual differences in a general framework of memory are discussed, and it is suggested that combined experimental and correlational approaches are needed to better understand individual differences in LTM and that individual differences in LTM should be used to better test and revise theories of LTM processes.

Public Significance Statement

This systematic review indicates that there are large and important individual differences in long-term memory. These individual differences are related to other important abilities including working memory, intelligence, and attention control.

Keywords: Individual differences, long-term memory, working memory

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Our ability to encode, store, and retrieve vast amounts of information in our memory system is one of the most important functions of our cognitive system. This memory system allows us to perform a number of important and routine tasks daily. Although our memory system is typically very efficient, sometimes failures occur that have minor or major consequences. Furthermore, the efficiency of the memory system differs across individuals. Even within the normal range of abilities there are large and important individual differences in memory abilities. Some of us find it difficult to remember names, dates, and other events from our lives, whereas others can seemingly remember the most mundane of past activities. These individual differences in memory abilities can result not only in fairly commonplace differences (such as differences in the ability to remember your e-mail password), but they can also give rise to differences related to more important real-world outcomes. For example, students with poor memory abilities will likely have difficulties learning and retrieving information in educational contexts leading to poor exam scores. Understanding the nature of this variation in memory abilities is critical not only for providing a better understanding of our memory system more broadly, but it is also important for potentially reducing memory problems for the less able.

Researchers have long been interested in the scientific study of memory processes (Ebbinghaus, 1885/1964) as well as individual differences in memory abilities (e.g., Jacobs, 1887; see also Blankenship, 1938). Indeed, in discussing memory abilities, Ebbinghaus (1885/1964) noted "how differently do different individuals behave in this respect! One retains and reproduces well; another, poorly" (p. 3). Although these two research areas have flourished over the past 100 years, there have been few attempts to integrate experimental and differential approaches despite this having been advocated by several researchers in both fields (Cohen, 1994; Cronbach, 1957; Kosslyn et al., 2002; Underwood, 1975). For example, at the conclusion of a conference on Learning and Individual differences in 1967, Arthur Melton noted:

> [T]he sooner our experiments and our theory on human memory and human learning consider the differences between individuals in our experimental analyses of component processes in memory and learning, the sooner we will have theories and experiments that have some substantial probability of reflecting the fundamental characteristics of those processes. (Melton, 1967, pp. 249–250)

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To better understand individual differences in memory, it is critical that experimental and differential methods be combined. In the present review, both of these methodologies will be considered to examine individual differences in memory abilities, how these abilities relate to other cognitive abilities, how these abilities are related to particular components of cognitive tasks, and how these abilities interact with various experimental manipulations (see the Appendix for an index of the organizational structure of the review).

Background

Individual differences in memory abilities have long interested psychologists and have played an integral role in psychometric batteries of intelligence (e.g., Binet & Simon, 1905; Terman, 1916). When examining correlations among various ability measures including various memory measures, a number of memory factors tend to be present and strongly correlate with other ability factors (Carroll, 1993). Furthermore, there is a long and rich history of examining individual differences in learning (see Ackerman, Kyllonen, & Roberts, 1999; Gagne, 1967; Kanfer, Ackerman, & Cudeck, 1989 for reviews) as well as examining individual differences in cognition based on more cognitive oriented frameworks (Hunt, Frost, & Lunneborg, 1973; Hunt, Lunneborg, & Lewis, 1975). Thus, the notion that there are important individual differences in memory abilities has been researched for a long time (see Bors & MacLeod, 1996; Kane & Miyake, 2008; MacLeod, 1979; MacLeod, Jonker, & James, 2014 for reviews). For example, Cohen (1994) suggested a zeroth law of memory such that “individuals differ reliably in their memory capacities” (p. 270). More recently, in discussing various principles of memory, Surprenant and Neath (2008) also suggested that individual differences in memory were a fundamental property. Yet, contemporary research on memory abilities still remains relatively scarce. That is, despite many calls in the literature for the need to examine individual differences in memory abilities more thoroughly, this remains a neglected area of research. Indeed, Carroll (1993) noted that “the available literature on individual differences in learning and memory abilities leaves much to be desired” (p. 302).

Jenkins’ Tetrahedral Model of Memory Experiments

Jenkins (1979) presented a tetrahedral model of memory experiments that suggested that the outcomes of experiments on memory are due to four interacting factors (see Figure 1; see Roediger, 2008, for an updated view). These factors include encoding conditions, to-be-remembered materials, retrieval conditions, and subject factors. The encoding factor refers to the fact that various aspects of encoding will undoubtedly influence performance. These include instructions to the participants (intentional versus incidental learning), various strategies that might be used (rehearsal, imagery, grouping, etc.), the setting the study is conducted in, and different activities participants might engage during encoding (judgments on the items, performing a dual-task during encoding). The materials factor refers to the different to-be-remembered items or events that are presented to the participant. These include variations in sensory modality (items seen versus heard), words, letters, numbers, sentences, pictures, or even answers to general knowledge questions. The retrieval factor refers to the type of task used to measure performance and retention. Jenkins referred to these as the criterial tasks. These include tasks like serial recall, free recall, cued recall, item recognition, source recognition, and various other judgments (e.g., judgments of frequency and recency). Finally, Jenkins suggested that subject factors will also influence performance. These subject factors include innate abilities, interest (interest in the materials, interest in the experiment), knowledge (prior knowledge with the materials, prior knowledge with the type of experiment being conducted or criterial task), motivation (motivation to do well on the current experiment), personality traits, as well as age. Similarly, Kelley (1964) noted “that an individual’s performance on a task or ‘test’ is determined in part by the abilities that are called for by the test and in part by the degree to which the individual himself possesses these abilities” (p. 1). Thus, Jenkins, a prominent researcher of learning, memory, and individual differences suggested that it was critical that experiments of memory take into consideration basic variation in subjects reflecting differences in abilities and other differential variables.

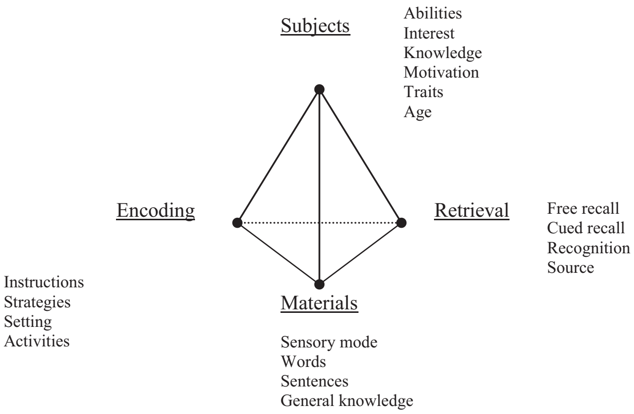

Figure 1. Jenkins’ tetrahedral model of memory experiments, suggesting that performance is determined by a combination of encoding, materials, retrieval, and subject factors. Adapted from “Four points to remember: A tetrahedral model of memory experiments,” by J. J. Jenkins, 1979, Hillsdale, NJ: Erlbaum. Copyright 1979 by Erlbaum; and From “Relativity of Remembering: Why the Laws of Memory Vanished,” by H. L., III, Roediger, 2008, *Annual Review of Psychology, 59,* pp. 225–254. Copyright 2009 by Annual Reviews, Inc. Adapted with permission.

Jenkins further noted that these different “variables interact vigorously with one another” (p. 431). That is, performance will depend on the particular combination of these four factors being manipulated and controlled. Thus, encoding and retrieval factors will interact and will tend to result in the best performance when there is a match between the two (Fisher & Craik, 1977; Morris, Bransford, & Franks, 1977; Tulving & Thomson, 1973). Importantly, subject factors will also likely interact in important ways with the other factors. For example, differences in memory abilities will interact with encoding factors to the extent that individuals can understand and adhere to the instructions. Likewise, memory abilities will interact with different types of retrieval tasks. Tasks that require more effort, attention, strategic control, and self-initiated processing may result in larger individual differences than tasks where more automatic processing can be used (Craik, 1983, 1986; Salthouse, 2001; Unsworth, 2009a). Furthermore, individual differences in motivation will likely be important in terms of how much effort and attention is allocated during encoding and retrieval resulting in differential performance (e.g., Kanfer & Ackerman, 1989). Thus, while examining individual differences in memory abilities it is critical that interactions with other variables are examined and considered to obtain a fuller account of variability between individuals. In the current review, some of these interactions will be examined in more detail, but much remains to be done.

Dual-Store Models of Memory

To frame our understanding of individual differences in memory abilities, we will need to consider not only how subject factors interact with other factors in memory experiments, but also how these differences fit in the context of memory theories. Perhaps the most prominent notion in memory theory is that there are two main memory states: working memory and long-term memory (Atkinson & Shiffrin, 1968; James, 1890; see Norris, 2017, for a recent review). The notion that there are separate memory systems for information over the short-term and the long-term is an old and enduring one (James, 1890). Many contemporary theories of memory suggest that a small subset of information can be actively maintained over the short-term via a working memory system, whereas the vast amount of information a person has at their disposal is usually stored in a long-term system (e.g., Healy & McNamara, 1996; Raaijmakers, 1993). Early theories of working memory (WM) and long-term memory (LTM) suggested that these two constructs represented qualitatively distinct and independent memory systems (e.g., Baddeley, 2007; Healy & McNamara, 1996; Jonides et al., 2008). In these theories, the WM system is responsible for maintaining and manipulating a small amount of information over a relatively short interval whereas the LTM system is responsible for maintaining all of the memories a person has acquired over the lifespan. The WM system also utilizes various control processes that are needed to maintain information in WM and to build strong and durable memories in LTM. For example, as suggested by Atkinson and Shiffrin (1968), these control processes include setting up a retrieval plan, selecting and utilizing appropriate encoding strategies, selecting and generating appropriate cues to search memory, as well as various monitoring strategies and decisions to continue searching or not. Thus, it was postulated that these two systems represented functionally different aspects of memory and had different properties and limits in terms of capacity and duration.

To differentiate these two constructs, there must be reliable and valid measures of both WM and LTM. Traditionally, two task characteristics have differentiated WM and LTM: number of to-be-remembered (TBR) items and retention interval (Cowan, 2008). Specifically, WM tasks usually consist of a set of TBR items that are within theoretical capacity limits (i.e., 4 ± 1, Cowan, 2001; 7 ± 2, Miller, 1956), whereas LTM tasks usually consist of a set of TBR items that exceed these capacity limits. Additionally, WM tasks are usually associated either with no retention interval (i.e., immediate recall) or with a very brief retention interval of only a few seconds (e.g., Cowan, 2008; Jonides et al., 2008; Ranganath, Johnson, & D'Esposito, 2003), whereas in LTM tasks the retention interval is usually much longer. Based on this distinction, research has found that there are large and important differences in WM and these differences are important predictors of performance on a wide array of laboratory and more real-world measures (Ackerman, Beier, & Boyle, 2002; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Cowan et al., 2005; Daneman & Carpenter, 1980; Engle & Kane, 2004; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Kyllonen & Christal, 1990; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002; Unsworth, 2016a; Unsworth & Engle, 2007; Unsworth, Fukuda, Awh, & Vogel, 2014).

Although there has been extensive research examining individual differences in WM, there is decidedly less research examining individual differences in LTM. The current review will primarily focus on natural variation in LTM abilities, rather than variation attributable to age or neuropsychological conditions. Much of the research that has been done examining LTM has focused on various list-learning tasks thought to tap episodic memory. In these tasks, participants are presented with lists of items at encoding which they are asked to remember for later. Following a delay period participants are given one out of several different types of memory tests. The tests include various recall tasks like free recall, serial recall, and cued recall in which participants are presented with a set of TBR items and after a brief delay are required to recall the TBR items. LTM may also be tested via various judgment tasks including item recognition, associative recognition, source recognition, judgments of frequency, and judgments of recency, to name a few. Unlike recall tests where items must be generated from memory, in different judgment tasks participants are presented with the items and must make different judgments about the items. These two types of tasks have a long history in memory research and have been used to elucidate the nature of different memory processes. As will be seen below, these different types of tasks have been used to examine individual differences in LTM abilities and their relation with WM and other cognitive abilities.

Methods and Approaches for Studying Individual Differences

To study individual differences in LTM abilities, one must rely on various different methods and approaches that will best address the specific question being asked (see Wingert & Brewer, 2018, for a recent review). Within the domain of individual differences there are two general types of studies: Cognitive correlates and cognitive components (Pellegrino & Glaser, 1979). First, the *cognitive correlates* approach seeks to specify correlations among various cognitive abilities. For example, to what extent are WM and LTM related to one another and to intelligence? In this approach measures of each putative construct are obtained and correlated to determine potential relations. This approach is also useful for examining potential unique sources of variance in a construct. For example, if WM and LTM are both related to intelligence is this because WM and LTM share considerable variance or are the relations independent with WM and LTM each contributing uniquely to the intelligence? This approach is also useful for examining possible mediation. For example, is the relation between LTM and intelligence attributable to WM? Second, the *cognitive components* approach investigates a particular cognitive task attempting to identify the various mechanisms that give rise to performance and examine whether there are individual differences in those components. For example, is variability in performance on free-recall tasks due in part to individual differences in encoding strategies? Both approaches are important and necessary for examining individual differences in LTM abilities because they provide a means of examining both construct representation (i.e., theoretical mechanisms that underlie performance) and nomothetic span (network of relations of task performance with other variables; Embretson, 1983).

In both approaches a number of different methods can be used to examine individual differences. Perhaps the simplest approach is to have participants perform tasks thought to tap the construct of interest (WM and LTM) and then simply examine whether performance on the two tests are correlated. This univariate method provides a simple way of assessing whether two theoretical constructs are related. However, because no task is a process-pure measure of the construct of interest and because single measures can be associated with poor psychometric properties (like poor reliability), a multivariate method can be beneficial. In this method multiple measures of each construct can be obtained and factor analysis can be used to examine relations among various tasks to determine whether there is sufficient common variance to form latent factors. For example, do WM measures load onto one factor and LTM measures onto a separate factor? Early research primarily relied on exploratory factor analysis which is a data-driven approach. More recent research relies on confirmatory factor analysis where relations among tasks and among factors are specified beforehand based on theory. Both methods allow for an examination of correlations at the latent factor level where measurement error has been reduced. Although knowing that two tasks or two factors correlate is important, we also want to know whether these relations are due to unique variance or due to shared variance with other constructs. To examine these types of issues regression techniques at the zero-order or latent level (e.g., structural equation modeling) are useful. With such techniques one can move beyond simply stating that there is a relation among constructs of interest, to specifying structural relations based on prior theory. All of these methods provide an assessment of the degree and magnitude of relations among various constructs of interest in line with cognitive correlates approach.

Another important method for examining individual differences in cognitive abilities is to combine correlational and experimental methods to assess various Aptitude × Treatment interactions. Cronbach and Snow (1977) and others (see Snow, 1991 for a review) argued for the importance of examining Aptitude × Treatment interactions where aptitude refers to characteristics of the individual and treatment refers to manipulated variables. In these types of designs a traditional experiment is conducted where generally a single dependent variable is examined for different experimental conditions and interactions with different person characteristics can be examined. For example, one may consider whether individual differences in LTM are greater under intentional learning conditions compared with incidental learning conditions. These types of studies seek to not only examine whether a relation exists between the individual differences variable and performance (a main effect), but to also examine how this relation changes as a function of various experimental manipulations. As Engle and Kane (2004) noted "the presumption is that if we can make the correlation appear and disappear with a given manipulation, some aspect of the manipulation controls the correlation" (p. 156). There are various methods for examining Aptitude × Treatment interactions including analysis of covariance, linear mixed models, multiple regression, and latent change and latent growth curve modeling. As reviewed throughout, both the cognitive correlates and cognitive components approaches and various different methodologies have been used to examine individual differences in LTM abilities.

Caveats to the Present Review

The present review will examine individual differences in LTM abilities by primarily examining normal variation in this cognitive ability. It is beyond the scope of the current review to examine variation attributable to age, personality, gender, or psychopathologies. Although each of these are likely important sources of variance in LTM abilities, the current focus is on normal cognitive abilities within a particular age range (young adults). Some studies will be examined that include a wide range of ages (19–90 e.g.), but the main focus will be on relations seen regardless of age. Furthermore, the current review will primarily focus on episodic LTM abilities given that much of the literature is concerned with list-learning tasks. Where appropriate other types of LTM will be examined, but there is a clear need for research examining individual differences in other types of LTM such as semantic memory, prospective memory, autobiographical memory, procedural memory, and implicit memory to name a few. See for example research by Ball et al. (2018), Brewer, Knight, Marsh, and Unsworth (2010), and Unsworth, Brewer, and Spillers (2012) examining individual differences prospective memory and research by LePort, Stark, McGaugh, and Stark (2017) on individuals with highly superior autobiographical memories. Furthermore, it is beyond the scope of the current review to review the long and important history of work done on learning and individual differences (see Ackerman et al., 1999; Gagne, 1967; Kanfer et al., 1989 for reviews). This work mainly examined changes in performance as a function of learning, whereas the current review is primarily focused on list-learning tasks where multiple learning episodes of the same information does not generally occur. Finally, throughout the paper I report reanalyzes of data sets from several published papers. Many of these reanalyses include data from my own laboratory and data from other studies that were accessible. This is a clear limitation of these analyses, and future research is needed to ensure their replicability and generalizability.

Factor Structure of LTM Abilities

One of the first and most heavily studied aspects of individual differences in LTM abilities is the factor structure of LTM. In these studies participants perform a large sample of different LTM tasks and factor analysis (primarily exploratory factor analysis for early studies) was used to examine the overall factor structure. Early work by Carothers (1921), Kelley (1928), Anastasi (1932), Carlson (1937), Garrett (1938), and Brener (1940) suggested the presence of one or more memory factors based on a number of different memory tests. In Thurstone's (1938) primary mental abilities one factor was specifically devoted to memory and consisted primarily of paired-associates test. Thurstone (1938) also included a word fluency factor relating to how quickly words could be retrieved from LTM. By 1940, Wolfe in his review of factor analysis up to that point suggested that a memory factor was the fourth most identified factor (Wolfe, 1940). In his review of the field in 1951, French suggested that there were four memory factors (Associated or Rote Memory, Musical Memory, Span Memory, and Visual Memory). Thus, when different memory tasks are utilized, scores on these tasks tend to correlate and form one or more factors potentially delineated by type of task and content of the materials.

Following French's (1951) review a number of additional factor analytic studies were done to better examine the overall factor structure. For example, Ingham (1952) had 80 participants perform eight different paired associates tasks and several intelligence measures. Factor analysis suggested the presence of a specific memory factor in addition to an overall g factor. In subsequent research Christal (1959) carried out a large-scale factor analytic study of visual memory (see Beier & Ackerman, 2004, for a reanalysis). In this Study 718 Air Force personnel completed 17 memory tests and 14 reference tests of ability (including tests of verbal abilities, mechanical knowledge, mathematic abilities, etc.). Factor analysis suggested the presence of four memory factors identified as Memory for Position in Space, Memory for Color, Memory for Position in Temporal Sequence, and Paired Associates Memory along with four additional ability factors (Mechanical Experience, Numerical Facility, Verbal Comprehension, and Perceptual Speed). Games (1962) had 100 university students perform 17 memory tests (primarily memory span or paired associates). A subsequent factor analysis suggested the presence of five factors including Memory Span and Rote Memory (which were correlated at $r = .32$). Building on the work of Christal (1959) and others, this work suggested the presence of separate memory factors.

In one of the largest studies of individual differences in memory, Kelley (1964) had 442 Air Force Cadets perform 27 different memory tests along with 13 reference tests of ability (see Beier & Ackerman, 2004, for a reanalysis). The memory tests consisted of recognition tests, paired associates tests, different tests of meaningful memory (e.g., remembering sentences, remembering stories, remembering limericks, etc.), memory span tests, and different visual memory tests (e.g., reproducing a geometrical design from memory, remembering map locations). Based on a factor analysis, Kelley identified 11 different factors. Of these, three were consistent memory factors of Rote Memory (paired associates), Memory Span, and Meaningful Memory. A fourth memory factor was identified as consisting of only paired associates of nonsense syllables. Finally, there was some indication of a fifth memory factor, but it was not clearly identified. Examining correlations among the memory factors suggested that Rote Memory and Meaningful memory factors were correlated ($r = .28$), but neither were related to the Memory Span factor (rs of $-.04$ and .06, respectively). Furthermore, the paired associates factor for nonsense syllables correlated with the Meaningful Memory factor ($r = .25$), but not with the Rote Memory factor ($r = .03$). Kelley suggested that these factors were somewhat general in that both visual and auditory presentations of the material were used and both recognition and recall (paired associates recall) were used. As such the results of this study provide some of the best evidence for different memory factors initially suggested by French (1951) and others.

Brown, Guilford, and Hoepfner (1968) tested aspects of Guilford's (1967) structure of intellect model in which it was hypothesized that there are 24 distinct memory abilities. Brown et al. had 175 eleventh graders perform 50 different ability tests. Brown et al. found six different memory factors, identified as Memory for Isolated Items, Memory for Class ideas, Memory for Meaningful Connections, Memory for Order, Memory for Transformations, and Memory for Arbitrary Connections. Hakstian and Cattell (1974) examined the existence of different primary abilities by administering 57 ability tests to 343 participants. Of these tests nine were fairly standard memory tests with six being paired associates and three being memory span tasks. The factor analysis suggested the presence of 19 factors of which three were memory factors. These were identified as Associative Memory (paired associates for simple stimuli like number-word pairs), Memory Span, and Meaningful Memory (paired associates for meaningful stimuli such as object-attribute pairs). Furthermore, they found that all three factors were correlated with one another (Associative Memory to Memory Span $r = .28$; Associative Memory to Meaningful Memory $r = .58$; Memory Span to Meaningful Memory $r = .20$). Thus, similar to prior research three distinct, yet correlated memory factors arose. Following up on this research Hakstian and Cattell (1978) administered 20 primary ability tests thought to tap each primary ability factor to 280 participants. Three of these tests represented the factors of Associative Memory, Memory Span, and Meaningful Memory. Hakstian and Cattell found that Associative Memory and Memory Span were correlated ($r = .23$), Associative Memory and Meaningful Memory were correlated ($r = .36$), and Memory Span and Meaningful Memory were correlated ($r = .14$). Importantly, they found evidence for a higher-order memory factor that they called General Memory Capacity. The highest loadings on this factor were Associative Memory (.66) and Meaningful Memory (.38). Interestingly, Memory Span loaded weakly on this factor (.11) and had its highest loading on the Perceptual Speed factor (.31). Hakstian and Cattell also found evidence for a higher-order factor that they called General Retrieval Capacity whose highest loadings were from an ideational fluency task (.78). This factor is similar to Thurstone's (1938) fluency factor. Hakstian and Cattell suggested that whereas the General Memory Capacity factor represented the ability to commit items to memory, the General Retrieval Capacity factor represented the ability to rapidly retrieve items from LTM that had already been committed to memory. Importantly these two higher-order factors were correlated ($r = .22$), suggesting some shared abilities. This study is important for not only examining different memory factors, but for also providing some of the first evidence for a more general higher-order memory factor.

In 1978 Underwood, Boruch, and Malmi conducted what is perhaps still the largest individual differences study of episodic memory. In this study 200 participants completed (over the course of 10 sessions) 28 different episodic memory tasks along with measures of vocabulary, spelling, and SAT scores. The episodic memory tests consisted of free recall, paired associates, recognition memory, serial learning, discrimination (list-discrimination, verbal discrimination; frequency discrimination), an interference susceptibility measure, and memory span tasks. Underwood et al. found evidence for five separate episodic memory factors. The first factor was identified as a paired associates factor given that all of the paired associates tasks loaded on it. Interestingly, the serial learning tasks also tended to load on this factor. The second factor was identified as a free recall factor with all of the free-recall tasks loading on it. This factor also had loadings from the serial learning tasks and from the list-discrimination task. The third factor was identified as a memory span factor. The fourth factor was identified as a recognition/frequency factor. Finally, the fifth factor was identified as a discrimination factor with the verbal discrimination tasks and list discrimination task loading on it. This study provides important evidence for distinct memory factors based on differences in the criterial tasks used (see also Malmi, Underwood, & Carroll, 1979). Whereas prior research primarily relied on different psychometric memory tests that had been used many times previously in factor analytic work, Underwood et al.'s study stands out for using more standard experimental tests of episodic memory. As such this study provides important evidence for the notion that the factor structure of LTM abilities is driven by abilities needed on different LTM tasks.

In his comprehensive review of factor analytic studies, Carroll (1993) summarized the prior research examining the factor structure of LTM (including the studies summarized here) and determined that a number of distinct factors were evident. Specifically, examining data from 117 different samples in memory abilities Carroll identified five first-order memory factors. These were *Memory Span* (identified in 70 data sets), representing the ability to recall items in their correct order. *Associative Memory* (identified in 51 data sets), representing the ability to form arbitrary associations. *Free Recall* (identified in 12 data sets), representing the ability to recall arbitrary information that exceeds the capacity of WM. *Meaningful Memory* (identified in 17 data sets), representing the ability to recall or recognize meaningful material. *Visual Memory* (identified in five data sets), representing the ability to remember visual information that is not easily transformed into a verbal code. Given the scare evidence for this factor, in later work Carroll (1994) did not include it as one of the primary first-order factors.

In reanalyzing the data, Carroll found that although there was evidence for five distinct memory factors, these factors tended to all correlate with one another, suggesting the presence of a common higher-order factor. Similar to prior work by Thurstone (1938) and Hakstian and Cattell (1978), Carroll (1993, 1994) also suggested a second-order general retrieval capacity indexing the ability to rapidly retrieve information from LTM. Collectively, this work suggests that not only are there distinct abilities that are required in different memory tests, but also that there are common abilities that are needed across a wide array of different memory tests and those individuals who score high on one test of memory tend to score high on other tests of memory.

More recent conceptualizations of human cognitive abilities also suggest the presence of both lower-order and higher-order memory factors. For example, the Cattell-Horn-Carroll theory is an integration of the Horn-Cattell fluid and crystallized intelligence theory with Carroll's (1993) three-stratum theory (McGrew, 2009; Schneider & McGrew, 2012). In this conceptualization, WM (labeled as short-term memory [STM]) and LTM (labeled as long-term storage and retrieval) are distinct higher-order factors. The general WM (or Gsm) factor represents the ability to apprehend and maintain in awareness a small number of items for immediate report. This factor is composed of simple and complex memory span tasks. The general LTM (or Glr) factor represents the ability to encode and store new information in LTM and to later fluently retrieve information from LTM. This general factor can be further broken down into Learning Efficiency and Retrieval Fluency factors. The learning efficiency factor is composed of tasks measuring Associative Memory, Free Recall, and Meaningful Memory, whereas the retrieval fluency factor is composed of various fluency tasks. Thus, whereas prior research combined WM and LTM into a more general memory factor, more recent conceptualizations suggest that these are separate and distinct higher-order factors and each of these higher-order factors can be further subdivided.

Following Carroll's (1993) review there has been a relative lull in examining the factor structure of LTM abilities. Despite this lull, a number of advances have been made. One important advance has been the reliance on confirmatory factor analysis rather than exploratory factor analysis. Much of the prior research relied on exploratory factor analysis which is primarily a data-driven process in which the factor structure is not specified a priori based on theory. In confirmatory factor analysis, however, the overall measurement model (loadings of measures onto factors and relations among factors) is specified based on prior theory. By testing various models one can better examine the theoretical structure of the data with confirmatory factor analysis. For example, Nyberg (1994) examined whether declarative memory could be broken down into episodic and semantic memory factors (see also Cohen, 1984; Mitchell, 1989). Nyberg (1994) had 300 participants perform multiple measures of free recall, cued recall, recognition, and various word fluency tasks. Nyberg found that a two-factor model differentiating episodic memory (free recall, cued recall, and recognition) from semantic memory (word fluency) fit the data better than a single factor memory model, consistent with a differentiation of learning efficiency and retrieval fluency. Nyberg et al. (2003) further examined whether semantic and episodic memory factors could be differentiated as well as whether these factors could be subdivided. Nine hundred twenty-five participants performed multiple recall, recognition, and fluency tasks along with measures of vocabulary and general knowledge. Nyberg et al. found that the best fitting model was one that assumed that there were distinct episodic and semantic memory factors and these two factors could be further subdivided into recall and recognition for episodic memory and knowledge and fluency for semantic memory. Furthermore, the episodic and semantic memory factors were strongly correlated ($r = .80$), suggesting the presence of a higher-order memory factor (see also Herrmann et al., 2001). Collectively, these studies suggest that LTM abilities can be differentiated in terms of episodic and semantic memory abilities, and these two tend to be correlated suggesting the presence of a higher-order memory factor.

Additional research has suggested that that there are likely differences based on the criterial tasks used. For example, Park et al. (1996) had 301 participants perform multiple memory measures and found that there were separate factors for span memory, free recall, cued recall, and source recall. These different factors were all interrelated, suggesting the possibility of a higher-order general factor. Unsworth (2009a) also found evidence for separate span memory (complex span tasks), free recall, and cued recall factors. Importantly, Unsworth found evidence for a single higher-order memory factor composed of lower order free recall (loading = .94), cued recall (loading = .69), and span memory (loading = .64) factors. Subsequent research has found a similar factor structure to the data. Unsworth (2010a) had 165 participants perform 14 memory measures and found that the best fitting model was one that assumed separate span memory, recall, and recognition memory factors. Furthermore, these three factors were all interrelated and a higher-order general memory factor could be formed from the three lower-order factors (span memory loading = .44; recall loading = .81; recognition loading = .89). In an additional study, Unsworth and Brewer (2009; see also Unsworth & Brewer, 2010a) had 172 participants perform 13 different memory tasks and found that a model with separate span memory, item recognition, source recognition, recall, and judgments of recency factors fit the data well. Furthermore, the different memory factors all tended to be moderately to strongly related. Thus, more recent research which has relied on confirmatory factor analyses has suggested that LTM abilities can be divided into episodic and semantic memory factors. Furthermore, the episodic memory factor can be further broken down into more task-specific factors. Importantly, all of these factors tend to correlate with one another suggesting the presence of a more general memory ability.

Best-Evidence Synthesis

As noted above, many prior factor analytic studies have relied on exploratory factor analysis to examine the structure of the data. Only recently has confirmatory factor analysis begun to be used to examine the adequacy of different configurations of the data. Carroll (1993) reanalyzed many of these data sets and found evidence for a higher-order factor in most of the data sets where more than one factor was obtained. Using modern confirmatory factor analysis and structural equation modeling techniques, Beier and Ackerman (2004) reanalyzed data from both the Christal (1959) and Kelley (1964) studies discussed earlier. Beier and Ackerman relied on a best-evidence synthesis (Slavin, 1986) in which select studies that provide the best evidence for a specific question are reexamined. That is, rather than reviewing and analyzing all possible studies on a topic, evidence from select studies thought to provide the best evidence on a topic is analyzed and synthesized. Beier and Ackerman used a best evidence synthesis to examine relations between memory span and LTM and found that a higher-order factor accounted for the lower-order memory factors.

To gain a better understanding of the factor structure of LTM abilities, five prior data sets were examined via a best-evidence synthesis. These studies were selected because they each had a relatively large number of participants who performed a large number of LTM tasks. Other potential studies were not utilized given that they had only a few LTM tasks, had participants across multiple age ranges, or did not provide a correlation matrix to allow for reanalysis. Of course the selection of these studies is somewhat biased by what is deemed the "best evidence," but as will be seen below the same general patterns emerge in multiple data sets. The goal was to examine whether factors based on criterial tasks could be formed and whether these factors correlated and could be accounted for by a higher-order general memory factor. The data sets that were reanalyzed were Underwood, Boruch, and Malmi (1978), Malmi et al. (1979), Nyberg (1994), Unsworth and Brewer (2009, 2010a), and Unsworth (2010a). The data were reanalyzed in two steps for each study. In the first step, a measurement model was specified in which tasks relying on the same testing format (free recall, paired associates, recognition, etc.) loaded on their own respective factors and the factors were allowed to correlate. In the second step, a higher-order factor was specified with each of the lower-order factors loading onto it. In each step a number of different fit indices were examined to determine whether the specified model fit the data.[1] Furthermore, although several of the data sets had memory span measures (either simple or complex span), these were not included in the reanalyses given that these are thought to be primarily measures of WM rather than LTM.

The first reanalysis focused on Underwood et al.'s (1978) large scale study in which 200 participants complete a large battery of episodic memory tasks. To examine the factor structure of the data a measurement model was specified for separate free recall, paired associates, serial learning, recognition, and discrimination factors. All of the factors were allowed to correlate with one another. The fit of the overall model was good, $\chi^2(125) = 229.20$, $p < .01$, RMSEA = .07, NNFI = .97, CFI = .98, SRMR = .06. As shown in Figure 2a, all of the latent factors were moderately to strongly correlated with one another. Given the correlations among the factors, next a higher-order factor model was specified such that each of the lower-order memory factors was allowed to load onto a single higher-order memory factor (LTM). The fit of the overall model was good, $\chi^2(130) = 244.66$, $p < .01$, RMSEA = .07, NNFI = .97, CFI = .98, SRMR = .06. As shown in Figure 2b, all of the lower-order factors strongly loaded onto the higher-order LTM factor with the strongest loadings occurring for FR, PA, and SL. These results strongly suggest that there is a general LTM factor and this factor can be further broken down into more task-specific factors. Similar results were obtained when reanalyzing Malmi et al. (1979; see supplemental materials).

Similar models were examined for Nyberg (1994), where first a measurement model was specified with separate free recall, cued recall, fluency, and recognition factors. All of the factors were allowed to correlate. Additionally, given that the cued recall and free-recall tasks shared the same methods, their error variances were allowed to correlate. The fit of the overall model was good, $\chi^2(27) = 28.58$, $p = .38$, RMSEA = .01, NNFI = .99, CFI = 1.00, SRMR = .03. As shown in Figure 3a, all of the latent factors were moderately to strongly correlated with one another. Specifying a higher-order factor model with the four lower-order factors suggested a good fit to the data, $\chi^2(29) = 29.74$, $p = .43$, RMSEA = .01, NNFI = .99, CFI = 1.0, SRMR = .03. As shown in Figure 3b, each of the lower order factors strongly loaded onto the general LTM factor. These results suggest that a broad LTM factor can be extracted not only from batteries composed of episodic memory tasks, but also from a combination of episodic list-learning tasks and fluency tasks thought to represent more general retrieval abilities.

Next, data from Unsworth and Brewer (2009, 2010a) were examined. Unsworth and Brewer (2009) examined relationships among item recognition, source recognition, and recall, whereas Unsworth and Brewer (2010a) were primarily concerned with examining individual differences in false recall (see below) via an

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[1] For all model testing (using Lisrel 8.80), several fit statistics are reported. Nonsignificant chi-square tests indicate adequate model fit; with large samples, however, they are nearly always significant. Comparative fit indices (CFI) and nonnormed fit index (NNFI) of ≥.90 indicate adequate fit, whereas the root mean square error of approximation (RMSEA) and standardized root mean square residual (SRMR) values of ≤.08 indicate adequate fit (e.g., Schermelleh-Engel, Moosbrugger, & Müller, 2003).

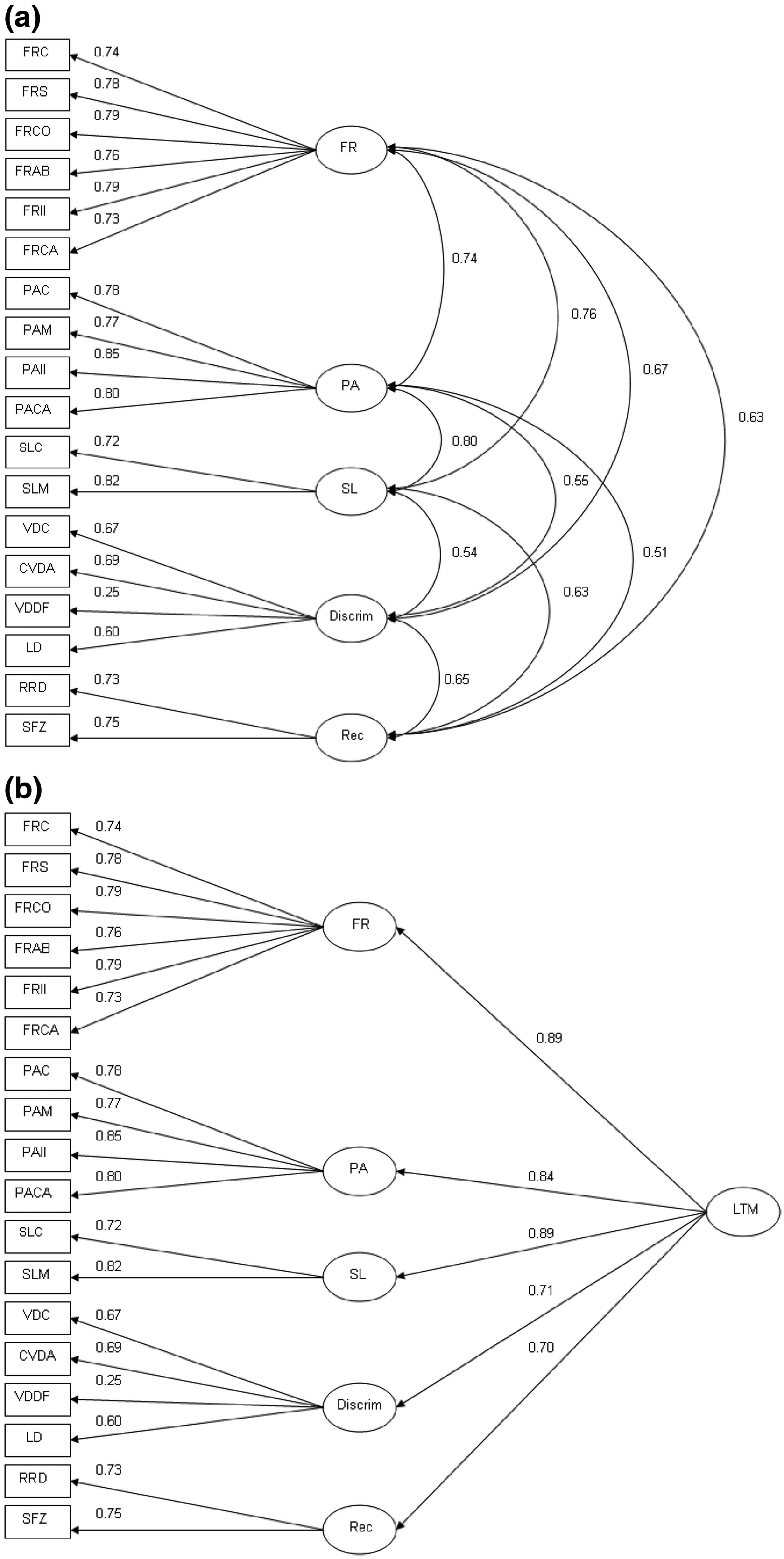

Figure 2 (*opposite*).

examination of intrusion errors in different recall tasks. The same overall dataset was used for both papers. Thus, it is examined here as a single dataset. A measurement model was specified with separate free recall, paired associate, source recognition, item recognition, and judgments of recency factors. All of the factors were allowed to correlate. The fit of the overall model was good, $\chi^2(44) = 59.32$, $p = .06$, RMSEA = .05, NNFI = .97, CFI = .98, SRMR = .05. As shown in Figure 4a, most of the latent factors (except the JOR factor) were moderately to strongly correlated with one another. Specifying a higher-order factor model with the five lower-order factors suggested a good fit to the data, $\chi^2(49) = 75.69$, $p < .01$, RMSEA = .06, NNFI = .96, CFI = .97, SRMR = .05. As shown in Figure 4b, paired associates, source recognition, and free recall strongly loaded onto the general LTM factor while the item recognition and judgments of recency factors loaded more weakly on the general factor. Similar results were obtained when reanalyzing Unsworth (2010a; see supplemental materials).

Reanalyzing several key data sets with confirmatory factor analytic techniques suggested that models assuming several distinct, yet correlated, memory factors based on relations among criterial tasks provided a good fit to the data. These factors tended to be based on free recall, paired associates, item recognition, source recognition, serial learning, and fluency tasks. Furthermore, in each dataset these distinct memory factors tended to correlate moderately to strongly allowing for a single higher-order general factor to be extracted. Collectively, the prior historical review and the best-evidence synthesis provide important evidence for the factor structure of LTM abilities based on several lower-order task specific factors and a more general LTM factor. This general LTM ability factor likely represents individual differences in a number of abilities that operate at encoding and retrieval. That is, similar to some conceptualizations of *g* (Detterman, 1994; Kovacs & Conway, 2016), this general LTM factor likely represents a number of distinct processes which contribute to performance on LTM tasks and which individuals differ on.

Relations With Other Cognitive Abilities

Having examined the overall factor structure of LTM abilities, I now examine how these abilities are related to other cognitive abilities such as WM, fluid and crystallized intelligence, and attention control. Assuming LTM abilities are needed in a host of other cognitive tasks and situations, one would expect that these abilities should be related to other important cognitive abilities. Indeed, LTM abilities strongly load onto an overall g-factor suggesting important shared variance between LTM abilities and other cognitive abilities. For example, analyses from the Woodcock-Johnson test battery (WJ-IV, McGrew, LaForte, & Schrank, 2014) suggests that LTM abilities (labeled as Glr) consistently have the strongest loading on the g-factor (median loading = .95 across age groups) with fluid intelligence having the second strongest loading (median loading = .94 across age groups). Similarly, Carroll (1994) reanalyzed data from Hakstian and Cattell (1974) and found that LTM abilities loaded highest on the third-order g-factor (.76) followed by gF (.62), gC (.52), and general retrieval (.22). Thus, LTM abilities seem to be a central source of common variance and it is critical to examine how these abilities are related to other cognitive abilities.

As noted previously, a common conceptualization of the memory system is to assume that there are separate systems for WM and LTM. However, these two systems interact with one another such that items that are maintained in WM can get encoded and stored into LTM with the help of various control processes. Furthermore, information from LTM can be also used during encoding to strengthen memories via associations. Thus, individuals with greater WM capacity should be able to hold and integrate more information in WM than low capacity individuals, leading to stronger LTM representations. Given that both memory factors represent aspects of the overall memory system and there are clear individual differences in both factors, it is important to examine the extent to which these two factors are correlated with one another. To do so, I examined data from 14 prior latent variable studies (with 2990 participants) that have included multiple measures of WM (simple span, complex span, etc.) and multiple measures of LTM (free recall, paired associates, recognition, etc.). I focused only on latent variable studies to ensure that the relations are based on latent factors rather than correlations between two tasks which could influence the overall relation due to poor psychometric properties of the tasks or idiosyncratic task effects. Furthermore, only studies with young adults were included. Studies had to have utilized multiple measures per construct and report the latent variable relations. Shown in Table 1 are the resulting correlations. As can be seen, WM and LTM are typically correlated at the latent level with correlations ranging from .33–.79. Furthermore, computing the mean-weighted correlation coefficients ($r+$; Hedges & Olkin, 1985) in Table 2 suggests that WM and LTM are correlated at the latent level ($r+ = .58$). Thus, there is a strong and consistent correlation between WM and LTM abilities at the factor level. Importantly, examining the 95% confidence intervals around this latent correlation suggests that the correlation is considerably less than 1.0, suggesting that although

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Figure 2 (*opposite*). (a) Confirmatory factor analysis with separate free recall (FR), paired associates (PA), serial learning (SL), discrimination (Discrim), and recognition (Rec) factors. Paths connecting latent variables (circles) to each other represent the correlations between the constructs and the numbers from the latent variables to the manifest variables (squares) represent the loadings of each task onto the latent variable. (b) Confirmatory factor analysis with a higher-order long-term memory (LTM) factors based on lower-order free recall (FR), paired associates (PA), serial learning (SL), discrimination (Discrim), and recognition (Rec) factors. All paths are significant at the $p < .05$ level. FRC = free recall control; FRS = free recall spacing; FRCO = free recall concrete; FRAB = free recall abstract; FRII = free recall interitem associations; FRCA = free recall conceptual associations; PAC = paired associates control; PAM = paired associates matching; PAII = paired associates crossed associates; PACA = paired associates conceptual interference; SLC = serial learning control; SLM = serial learning positioning; VDC = verbal discrimination control; CVDA = verbal discrimination affective cuing; VDDF = verbal discrimination double functions; LD = list-discrimination; RRD = running recognition; SFZ = situational frequency. Data from Underwood et al. (1978).

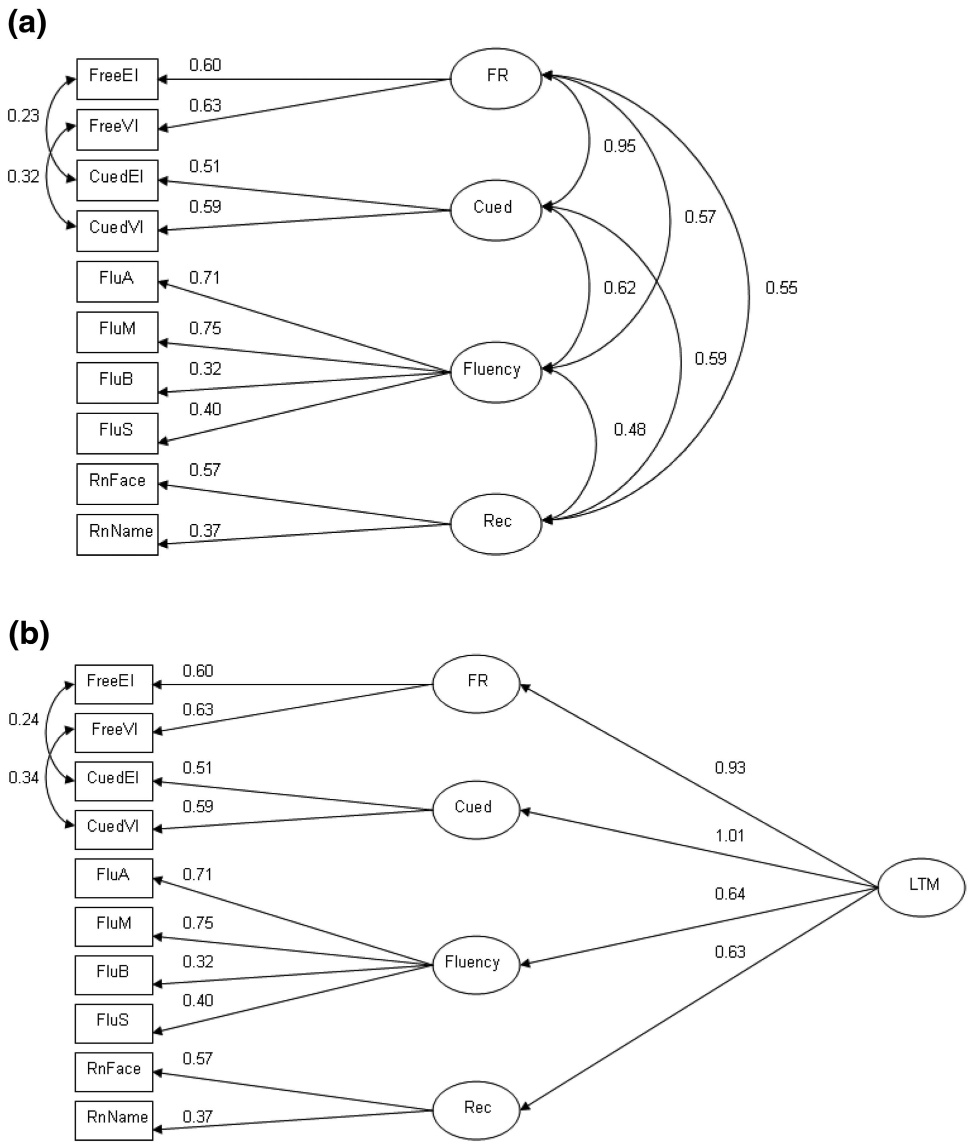

Figure 3. (a) Confirmatory factor analysis with separate free recall (FR), cued recall (Cued), fluency, and recognition (Rec) factors. Paths connecting latent variables (circles) to each other represent the correlations between the constructs and the numbers from the latent variables to the manifest variables (squares) represent the loadings of each task onto the latent variable. (b) Confirmatory factor analysis with a higher-order long-term memory (LTM) factors based on lower-order free recall (FR), cued recall (Cued), fluency, and recognition (Rec) factors. All paths are significant at the $p < .05$ level. FreeEI = enacted instructions; FreeVI = free recall verbal instructions; CuedEI = cued recall enacted instructions; CuedVI = cued recall verbal instructions; FluA = fluency words beginning with letter A; FluM = fluency five words long beginning with letter M; FluB = fluency professions beginning with letter B; FluS = fluency five-letter long names of animals beginning with letter S; RnFace = recognition memory faces; RnName = recognition memory names. Data from Nyberg (1994).

WM and LTM abilities are related, they are also distinct (Unsworth, 2010a; Unsworth, Brewer, & Spillers, 2009). These results are consistent with current conceptualizations of human cognitive abilities suggesting separate WM and LTM factors (McGrew, 2009; Schneider & McGrew, 2012).

Relations with intelligence were also examined. Much prior research has suggested a strong and consistent correlation between WM and intelligence (e.g., Ackerman, Beier, & Boyle, 2005; Kane, Hambrick, & Conway, 2005). Indeed, most studies of WM start with a statement indicating that WM is important for higher-order cognition. It is also the case that LTM abilities are related to and important for higher-order cognitive constructs like intelligence. Yet, recent research focuses on the relation between WM and intelligence, suggesting that LTM abilities are not as important. Indeed, Baddeley (2007) noted that "working memory span also predicts cognitive functioning much more effectively than

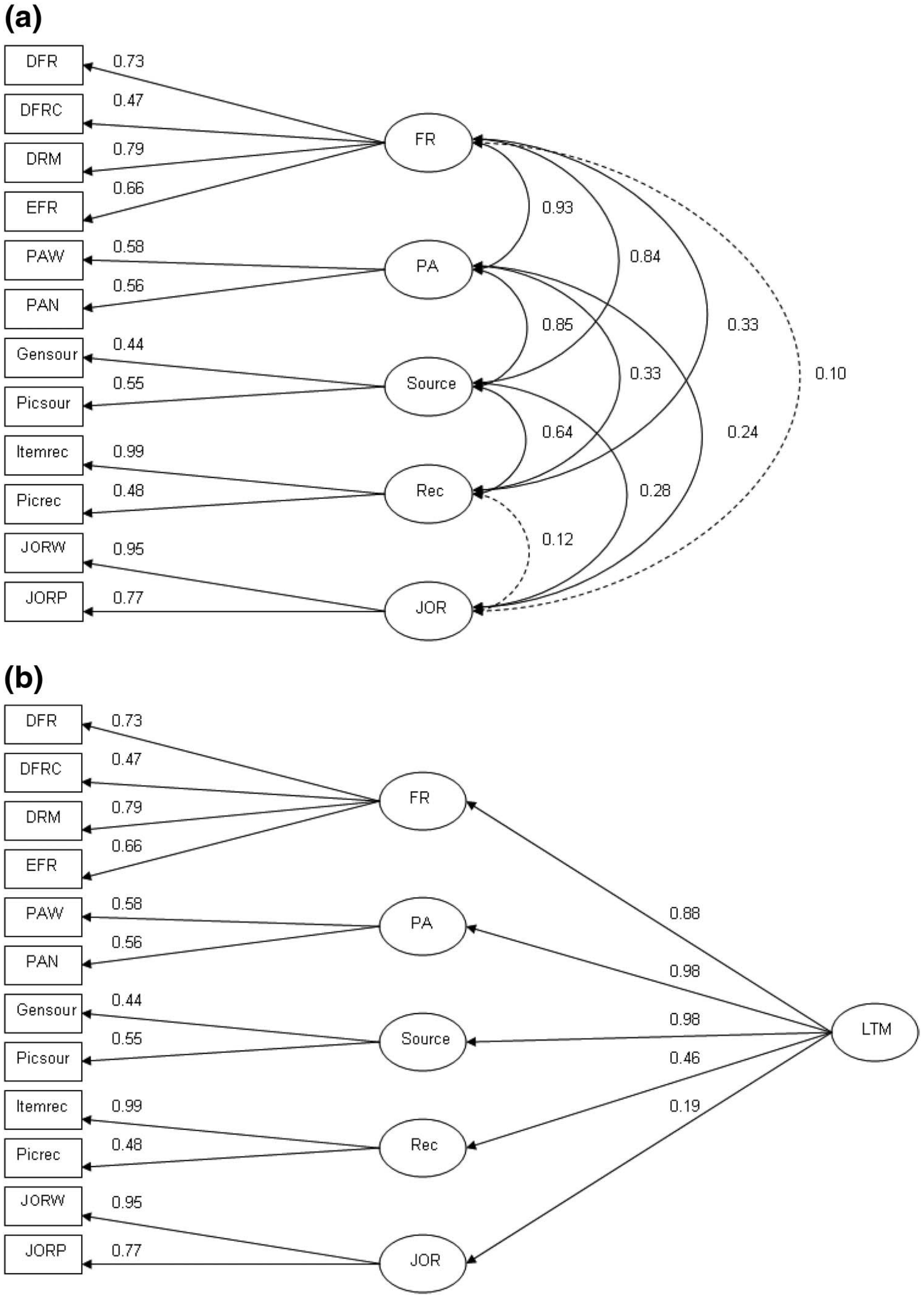

Figure 4. (a) Confirmatory factor analysis with separate free recall (FR), paired associates (PA), source recognition (Source), item recognition (Rec), and judgments of recency (JOR) factors. Paths connecting latent variables (circles) to each other represent the correlations between the constructs and the numbers from the latent variables to the manifest variables (squares) represent the loadings of each task onto the latent variable. (b) Confirmatory factor analysis with a higher-order long-term memory (LTM) factors based on lower-order free recall (FR), paired associates (PA), source recognition (Source), item recognition (Rec), and judgments of recency (JOR). Solid paths are significant at the $p < .05$ level, whereas dashed paths are not significant. DFR = delayed free recall; DFRC = delayed free recall with category switches; DRM = delayed free recall with Deese-Roediger-McDermott lists; EFR = externalized free recall; PAW = paired associates with words; PAN = paired associates with numbers; Gensour = gender source recognition; Picsour = picture source recognition; Itemrec = item recognition words; Picrec = picture recognition; JORW = judgments of recency words; JORP = judgments of recency pictures. Data from Unsworth and Brewer (2009, 2010a).

Table 1
Latent Factor Correlations Between Long-Term Memory and Other Cognitive Abilities Derived From Select Latent Variable Studies

		Latent factor correlations					
Study	*N*	g	gF	gC	WM	AC	SAT
Brewer and Unsworth (2012)	107		.40		.62	.41	
Christal (1959)[a]	718	.71					
Hakstian and Cattell (1978)	280		.17	.31			
Kelley (1964)[a]	442	.44			.47		
Mogle, Lovett, Stawski, and Sliwinski (2008)	383		.58		.76		
Shelton, Elliott, Matthews, Hill, and Gouvier (2010)	172		.57		.55		
Shipstead, Lindsey, Marshall, and Engle (2014)	215		.73		.55	.70	
Spillers (2017)	213				.54	.47	
Underwood, Boruch, and Malmi (1978)[b]	200			.33	.33		.19
Unsworth (2009a)[b]	137		.48		.62		
Unsworth (2010a)[b]	165		.55	.27	.37		
Unsworth and Brewer (2009, 2010a)[b]	177		.50	.20	.38		
Unsworth and Spillers (2010a)[b]	181		.45		.66	.59	
Unsworth, Brewer, and Spillers (2012)	165				.54	.62	.30
Unsworth, Brewer, and Spillers (2014)	171		.79		.57	.59	
Wilhelm, Hildebrandt, and Oberauer (2013)	262		.78		.79		

Note. g = general intelligence; gF = fluid intelligence; gC = crystallized intelligence; WM = working memory; AC = attention control; SAT = Scholastic Aptitude Test scores.
[a] Based on Beier and Ackerman (2004). [b] Based on a higher-order factor analysis of the memory tasks.

measures of either simple word span or episodic LTM" (p. 146). This clearly suggests that WM, but not LTM, is related to intellectual functioning. But, where is the evidence for such a claim? Here the extent to which LTM abilities are related to intelligence is examined more thoroughly. Consistent with current conceptualizations of cognitive abilities, fluid (gF) and crystallized (gC) intelligence were examined separately. Additionally, a few studies specifically examined relations with SAT scores (which are highly correlated with intelligence; Frey & Detterman, 2004), so those relations were also examined. Examining relations with gF, identified 11 prior latent variable studies (with 2250 participants). As can be seen in Table 1, gF and LTM abilities were moderately to strongly related across the studies with the latent factor correlations ranging from .17–.79. Examining the mean-weighted correlation suggested that gF and LTM were correlated at the latent factor level across studies ($r+ = .58$), and this correlation was as strong as the correlation between WM and LTM. Furthermore, the LTM-gF mean-weighted correlation was similar to the WM-gF mean-weighted correlation from the same sample of studies ($r+ = .61$, UL/LL = .58/.63). Thus, when examining gF, the current results suggest that LTM and WM demonstrate similarly strong relations with fluid reasoning, which is inconsistent with some prior claims.

Table 2
Mean-Weighted Latent Factor Correlations Between Long-Term Memory and Other Cognitive Abilities Derived From Select Latent Variable Studies

Variable	g	gF	gC	WM	AC	SAT
r+	.62	.58	.28	.58	.58	.24
LL/UL	.59/.66	.55/.60	.22/.35	.56/.61	.54/.62	.14/.33
N	1160	2250	822	2990	1052	365
k	2	11	4	14	6	2

Note. $r+$ = mean-weighted correlation coefficient; *LL/UL* = Lower limit/upper limit of 95% confidence interval of $r+$; WM = working memory; AC = attention control; SAT = Scholastic Aptitude Test scores.

In terms of gC, four studies were identified (with 822 participants). Unlike the other latent factor correlations, the correlations between gC and LTM were much weaker (ranging from .20–.33) with the mean-weighted correlation suggesting a weak latent factor correlation ($r+ = .28$). A similar pattern was found examining SAT in which two studies were identified (with 365 participants). Here the correlations ranged from .19–.30, and the mean-weighted correlation suggested weaker latent factor correlation ($r+ = .24$). Furthermore, Beier and Ackerman (2004) in their reanalysis of Christal (1959) and Kelley (1964) examined the relations between LTM and a higher-order g-factor. As seen in Table 1 these correlations were quite strong and the mean-weighted latent factor correlation was strong ($r+ = .62$). Thus, whereas LTM was strongly related to WM, gF, and overall g, LTM abilities demonstrated much weaker relations with gC and SAT (e.g., Unsworth, 2010a). Collectively, these results suggest that LTM abilities are related with WM and intelligence and the LTM-intelligence relations are on par with the WM-intelligence relations.[2]

Next, relations between LTM and attention control abilities were examined. Attention control refers to the set of processes that allow us to focus selectively and actively maintain task relevant information in the presence of internally or externally distracting information. Attention control processes are likely important for LTM abilities in terms of ensuring that attention is focused only on

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[2] In a recent dissertation, Spillers (2017) found that both WM ($r = .39$) and LTM ($r = .66$) were related to a reading comprehension latent factor and LTM mediated the relation between WM and reading comprehension. Thus, LTM abilities seem just as important to a number of higher-order cognitive abilities as WM abilities.

the relevant stimuli at encoding (not on distracting stimuli or task-unrelated thoughts; Maillet & Rajah, 2013, 2014; Smallwood, Baracaia, Lowe, & Obonsawin, 2003). Attention control processes are also needed to ensure that attention is properly allocated at encoding (e.g., Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Kane & Engle, 2000) and retrieval (e.g., Kane & Engle, 2000; Rohrer & Pashler, 2003). Thus, it is likely that LTM and attention control abilities should be related to the extent that attention control abilities partially determine variations in performance on LTM tasks. Likewise, LTM abilities might be important for performance on various attention control tasks to the extent that maintaining trial history and selection history is important for determining attention control settings (Awh, Belopolsky, & Theeuwes, 2012). Six latent variable studies were identified (with 1052 participants). As seen in Table 1, the correlations between LTM and attention control were moderately strong with correlations ranging from .41–.70. Furthermore, as shown in Table 2, the mean-weighted correlation between LTM and attention control was strong ($r+ = .58$). This correlation is consistent with prior research suggesting a relation between WM and attention control (e.g., Unsworth & McMillan, 2014; Unsworth & Spillers, 2010a; Kane et al., 2016). In fact, the correlation between LTM and attention control was of similar magnitude as the mean-weighted correlation between WM and attention control from the same sample of studies ($r+ = .55$).

These results suggest that LTM abilities are related to a number of other cognitive abilities and suggest that these relations are of a similar magnitude as those seen between WM and other cognitive abilities (gF, attention control). Thus, individual differences in LTM abilities are as important as WM in predicting other cognitive abilities. However, given that WM and LTM demonstrate moderately strong relations, it is possible that the relations between LTM and gF and attention control are actually due to shared variance with WM. That is, are the relations between LTM and gF and attention control due solely to shared variance with WM or does LTM predict unique variance in gF and attention control once WM is accounted for? To examine this, data from prior studies were reanalyzed testing various mediation models to see whether LTM would predict various cognitive abilities (specifically gF and attention control) once shared variance with WM was accounted for.

Relations with gF were examined by reanalyzing data from Unsworth and Brewer (2009, 2010a). First, a mediation model was specified in which LTM (based on 10 tasks) predicted WM (based on three tasks), and both LTM and WM predicted gF (based on three tasks). The fit of the model was acceptable, $\chi^2(101) = 182.76$, $p < .01$, RMSEA = .07, NNFI = .91, CFI = .92, SRMR = .07. As shown in Figure 5a, LTM predicted WM, and both WM and LTM predicted gF. That is, part of the relation between LTM and gF was due to shared variance with WM (indirect effect of LTM on gF = .20, $t = 2.93$), but LTM had a direct effect on gF even after accounting for WM (see also Unsworth et al., 2009). In fact, fixing the path from LTM to gF to zero resulted in significantly worse model fit ($\Delta\chi^2[1] = 5.34$, $p = .021$). This suggests that the strong relation seen between LTM and gF was not solely attributable to shared variance with WM. LTM abilities account for unique variance in gF over and above that accounted for by WM. Another way of examining this is to specify a bifactor model in which one factor is composed of all of the common variance shared by WM and LTM, and another factor is composed of the LTM-specific variance only. These two factors were both allowed to predict gF to get a sense of the common and unique contributions. The fit of this model was acceptable, $\chi^2(92) = 165.15$, $p < .01$, RMSEA = .07, NNFI = .91, CFI = .93, SRMR = .06. As shown in Figure 5b, the common factor strongly predicted gF. Importantly, the LTM-specific factor also predicted gF. Again, this suggests that LTM abilities predict gF, even when taking into account shared variance with WM. Very similar results were obtained when reanalyzing Unsworth (2010a) and Shelton, Elliott, Matthews, Hill, and Gouvier (2010). As such, these results provide evidence for the notion that LTM abilities are uniquely related to fluid abilities.

Relations with attention control were examined by reanalyzing data from Unsworth and Spillers (2010a). This dataset includes data from a large number of participants who all performed multiple measures of LTM, WM, and attention control, along with measures of gF. First, a mediation model was specified in which LTM (based on five tasks) predicted WM (based on three tasks), and both LTM and WM predicted attention control (based on four tasks). The fit of the model was acceptable, $\chi^2(51) = 75.63$, $p = .01$, RMSEA = .05, NNFI = .93, CFI = .95, SRMR = .06. As shown in Figure 6a, LTM predicted, WM, and both WM and LTM predicted attention control. Thus, part of the relation between LTM and attention control was due to shared variance with WM (indirect effect of LTM on attention control = .15, $t = 1.98$), but LTM had a direct effect on attention control even after accounting for WM. Fixing the path from LTM to attention control to zero resulted in significantly worse model fit ($\Delta\chi^2(1) = 10.49$, $p < .001$). Thus, LTM abilities accounted for unique variance in attention control over and above that accounted for by WM. Next a bifactor model was specified in which one factor was composed of all of the common variance shared by WM and LTM, and another factor is composed of the LTM-specific variance only. These two factors were both allowed to predict attention control. The fit of this model was acceptable, $\chi^2(47) = 67.36$, $p = .027$, RMSEA = .05, NNFI = .94, CFI = .96, SRMR = .05. As shown in Figure 6b, the common factor strongly predicted attention control. Additionally, the LTM-specific factor also predicted attention control. Very similar results were obtained when reanalyzing Unsworth et al. (2012), Unsworth et al. (2014), and Shipstead, Lindsey, Marshall, and Engle (2014). Collectively, these results provide evidence that LTM abilities are uniquely related to attention control abilities.

Examining relations between LTM abilities and other cognitive abilities in a number of latent factor studies suggested that LTM abilities were moderately to strongly correlated with WM, gF, and attention control abilities, but demonstrated much weaker relations with gC and SAT scores. Furthermore, the relations between LTM abilities and gF and attention control were not solely due to shared variance with WM. Rather, LTM abilities accounted for unique variance in each construct over and above shared variance with WM. These results provide important evidence for the notion that LTM abilities are important predictors of other cognitive abilities contrary to what prior research has assumed (e.g., Baddeley, 2007). As such, these results suggest a promising avenue of future research aimed at examining the predictive power of individual differences in LTM abilities.

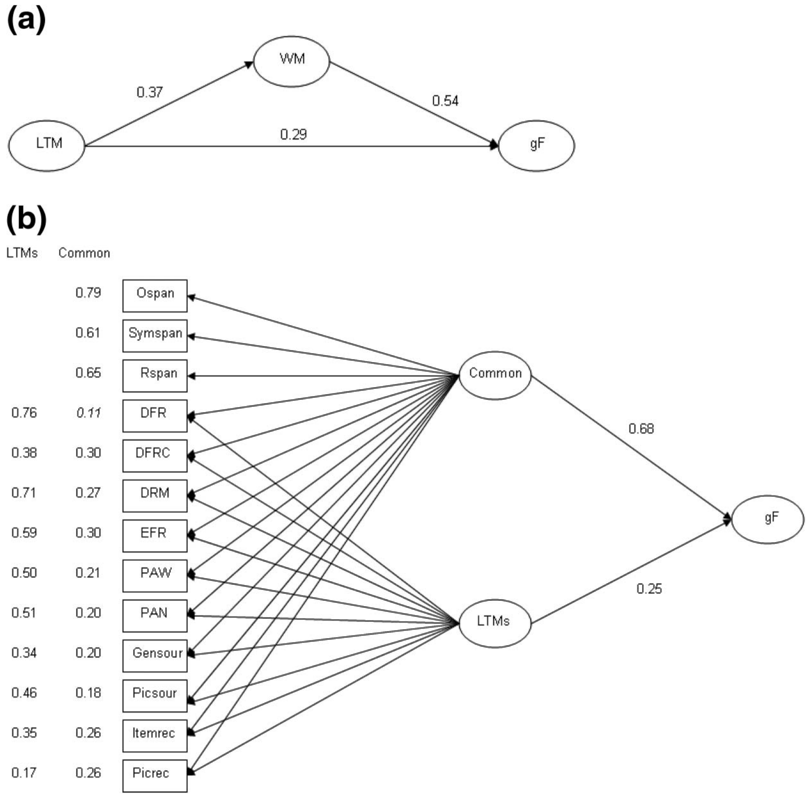

Figure 5. (a) Structural equation model for long-term memory (LTM), working memory (WM), and fluid intelligence (gF). Single-headed arrows connecting latent variables (circles) to each other represent standardized path coefficients indicating the unique contribution of the latent variable. (b) Structural equation model for the common variance shared across all the memory tasks (Common) and the variance specific to only the long-term memory tasks (LTMs) predicting fluid intelligence (gF). Italicized loadings are not significant at the $p < .05$ level, all other paths and loadings are significant at the $p < .05$ level Ospan = operation span; Symspan = symmetry span; Rspan = reading span; DFR = delayed free recall; Gensour = gender source recognition; Picrec = picture recognition; Picsour = picture source recognition; Itemrec = item recognition words. Data from Unsworth and Brewer (2009, 2010a).

Criterial Tasks

The preceding review suggests that many different LTM tasks correlate well with one another and tend to load on task-specific factors, which in turn are accounted for by a higher-order general LTM factor. Typically a single summary score is obtained for each task (most likely overall proportion correct) and this measure is correlated with a similar measure from another task. Although this provides important information in terms of individual differences in overall performance, there are several different ways in which someone may score poorly on any given measure. Two individuals may have the same summary score, but how they achieved that score may be very different. For example, in free recall two participants may both have recalled 50% of the items, but one participant may have primarily recalled primacy items, whereas another participant primarily recalled recency items. Therefore, a more fine-grained examination of differences in each type of task can be informative in terms of elucidating various different patterns of individual differences in LTM abilities.

Free Recall

In free-recall tasks participants are presented with a list of items (typically one at a time) and are asked to recall those items in any order they want. Variations of free recall are typically based on whether recall is required immediately (immediate free recall), whether there is a filled-distractor interval following the last TBR item (delayed free recall), or whether there are distractors intervening between each TBR item (continuous distractor free recall). Individual differences in free recall have been shown to be related to other cognitive abilities including WM, gF, and gC (Bors & Forrin, 1995; Healey, Crutchley, & Kahana, 2014; Unsworth, 2009b, 2010a; Unsworth, Brewer, et al., 2009). For example, Unsworth (2009b) found that a latent free recall factor (based on accuracy across three free-recall tasks) correlated with WM (r = .39) and gF (r = .42). Thus, prior research suggests that free-recall tasks tend to correlate moderately well with other cognitive abilities. These results call into question claims that basic free recall and other associative memory tasks are not related to intelligence or are only weakly related to intelligence (e.g., Mackintosh, 2011; Williams & Pearlberg, 2006).

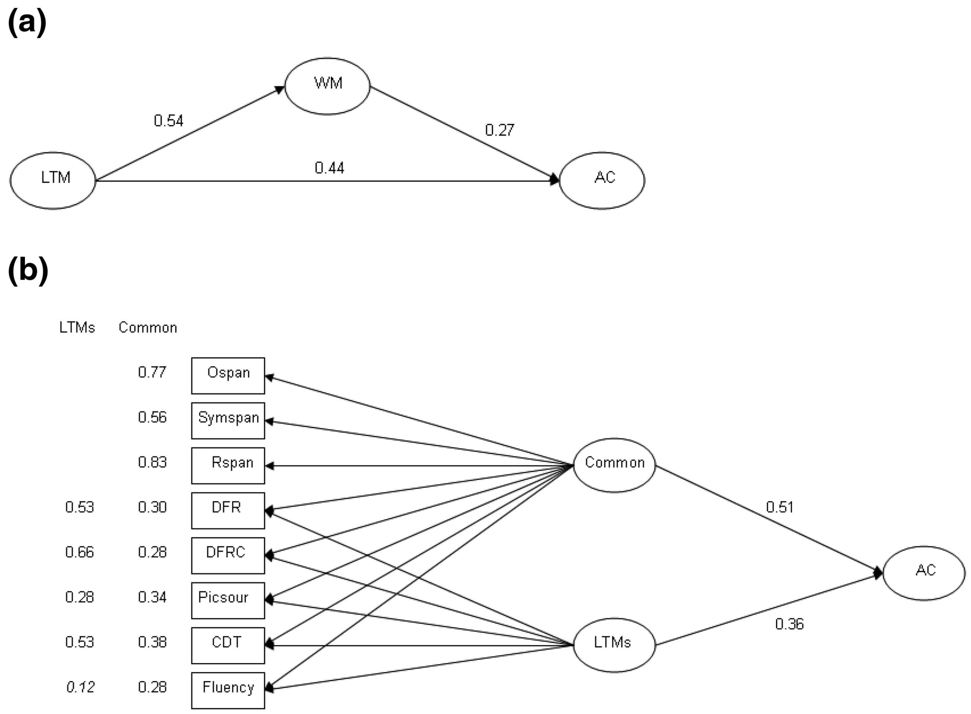

Figure 6. (a) Structural equation model for long-term memory (LTM), working memory (WM), and attention control (AC). Single-headed arrows connecting latent variables (circles) to each other represent standardized path coefficients indicating the unique contribution of the latent variable. (b) Structural equation model for the common variance shared across all the memory tasks (Common) and the variance specific to only the long-term memory tasks (LTMs) predicting attention control (AC). Italicized loadings are not significant at the $p < .05$ level, all other paths and loadings are significant at the $p < .05$ level Ospan = operation span; Symspan = symmetry span; Rspan = reading span; DFR = delayed free recall; Picsour = picture source recognition; DFRC = delayed free recall with category switches. Data from Unsworth and Spillers (2010a).

Across different free-recall tasks, the primary pattern that is examined is the serial position curve where the frequency of correctly recalling an item is plotted based on its position within the list. In standard immediate free recall, a U-shaped serial position curve is typically seen where items at the beginning of the list (primacy) and end of the list (recency) tend to be better recalled than items from the middle of the list (Deese & Kaufman, 1957; Murdock, 1962). In delayed free recall where participants have to perform a distracting task before recall, the primacy effect remains, but the recency effect is eliminated (Glanzer & Cunitz, 1966; Postman & Phillips, 1965). However, in the continuous distractor task (Poltrock & MacLeod, 1977), where distractor items occur before and after the presentation of each item, both primacy and recency effects are found (Bjork & Whitten, 1974). This overall pattern of results has been extensively debated in the literature. One popular account is that in immediate free recall recency items are maintained in WM allowing for near perfect recall of these items (Atkinson & Shiffrin, 1968). Primacy effects, however, are attributable to recall from LTM in which the first items receive the most rehearsals (Rundus, 1971) or the most attention leading to stronger items in LTM. In delayed free recall, the distractor task is thought to empty WM, resulting in a reduced recency effect. However, the reappearance of recency in the continuous distractor task has been harder to explain. Some dual-store theories suggest that recency effects seen in immediate free recall and continuous distractor free recall are different (short-term recency and long-term recency) with short-term recency being due to recall from WM and long-term recency being due to contextual retrieval from LTM (e.g., Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005; Raaijmakers, 1993). Other theories suggest that recency effects across different tasks are due to the same underlying mechanism, and thus they are not fundamentally different (Brown, Neath, & Chater, 2007; Sederberg, Howard, & Kahana, 2008).

Several studies have taken an individual differences approach to examining this question. Robertson-Tchabo and Arenberg (1976) had participants perform a number of tasks including immediate and delayed free recall. Robertson-Tchabo and Arenberg found that the prerecency and delayed free recall measures loaded onto one factor, whereas the recency score loaded onto a separate and nearly uncorrelated factor (see Carroll, 1993 for a reanalysis). Similar results have been obtained from subsequent studies. Bemelmans, Wolters, Zwinderman, ten Berge, and Goekoop (2002) examined serial position curves in two large samples of psychiatric patients and found that two factors (one for recency and one for prerecency) accounted for the data. Unsworth, Spillers, and Brewer (2010) also found evidence for separate prerecency and recency factors. These results suggest that two factors (which tend to be uncorrelated or correlated weakly) account for individual differences in immediate free recall. Luo (1993) examined whether two factors would account not only for immediate free recall serial position curves, but also for continuous distractor free recall. Luo (1993) found that two factors accounted for immediate free recall. Importantly, only one factor accounted for serial position effects in continuous distractor free recall. Furthermore, and similar to Robertson-Tchabo and Arenberg (1976), all serial positions in the continuous distractor task were correlated with prerecency serial positions in immediate free recall, but were uncorrelated with recency serial position effects in immediate free recall. These results are consistent with the notion that different mechanisms give rise to recency effects in immediate and continuous distractor free recall.

Not only can we use individual differences analyses to examine whether one or two factors underlie performance on free-recall tasks, we can also examine where individual differences in LTM abilities are differentially related to serial position. For example, do high and low LTM individuals differ at all serial positions (a main effect of LTM abilities), or do differences increase or decrease across serial positions (a serial Position × LTM ability interaction)? Furthermore, does the pattern of results change as a function of the type of free-recall task (immediate versus delayed) that is used? Examining immediate free recall, prior research has suggested a great deal of variability in terms of individual serial position functions (Healey & Kahana, 2014; Lehman & Malmberg, 2013; Unsworth, Brewer, & Spillers, 2011a). For example, Unsworth, Brewer, and Spillers (2011a) found that some participants primarily recalled recency items with little primacy, whereas other participants primarily recalled primacy items with little to no recency, and finally a third general group of participants recalled primacy and recency items relatively equally. Participants also performed a number of other tasks including a delayed free-recall task with category switches (to induce proactive interference build and release effects). Using the delayed free-recall task as a measure of LTM we can further examine how LTM abilities are related to immediate free recall serial position curves. Specifically, entering overall accuracy on the delayed free-recall task as a covariate in an analysis of covariance suggests not only a main effect of LTM, $F(1, 148) = 26.82$, $MSE = .10$, $p < .001$, partial $\eta^2 = .15$, in which immediate and delayed free recall were correlated ($r = .38$), but also an interaction between LTM abilities and serial position, $F(9, 1332) = 3.79$, $MSE = .03$, $p < .001$, partial $\eta^2 = .03$. As shown in Figure 7, examining the top (High LTM) and bottom (Low LTM) 25% of participants on the delayed free-recall task, suggests large differences for primacy items, but no differences for the last few recency items. Indeed, correlations between overall accuracy on the delayed free-recall task and serial position in the immediate free-recall task are moderate for early serial positions, but near zero for recency items (serial position 1 $r = .31$, serial position 2 $r = .32$, serial position 3 $r = .29$, serial position 4 $r = .25$, serial position 5 $r = .35$, serial position 6 $r = .32$, serial position 7 $r = .25$, serial position 8 $r = .15$, serial position 9 $r = -.01$, serial position 10 $r = -.04$). Consistent with dual-store models of memory, LTM abilities were related to prerecency portions of the serial position curve, but not to the recency portion for immediate free recall.

Additional research has suggested that primacy and recency components of the immediate free recall serial position curve are differentially related to cognitive abilities. For example, Horn, Donaldson, and Engstrom (1981) found that both primacy and recency were correlated with gF and gC, although the correlations tended to be somewhat stronger for primacy than for recency. Crawford and Stankov (1983) found that primacy was related to gC and speed of processing, but not to gF. Recency, however, was related to all three constructs. Unsworth et al. (2010) found that both primacy and recency were related to WM and gF, with the primacy relations being somewhat stronger than the recency relations. Similarly, Krueger and Salthouse (2011) found that primacy was strongly related to LTM, but weakly related to gF, gC, and speed of processing. The only relation with recency was with LTM abilities. Thus, primacy and recency are related to various cogni-

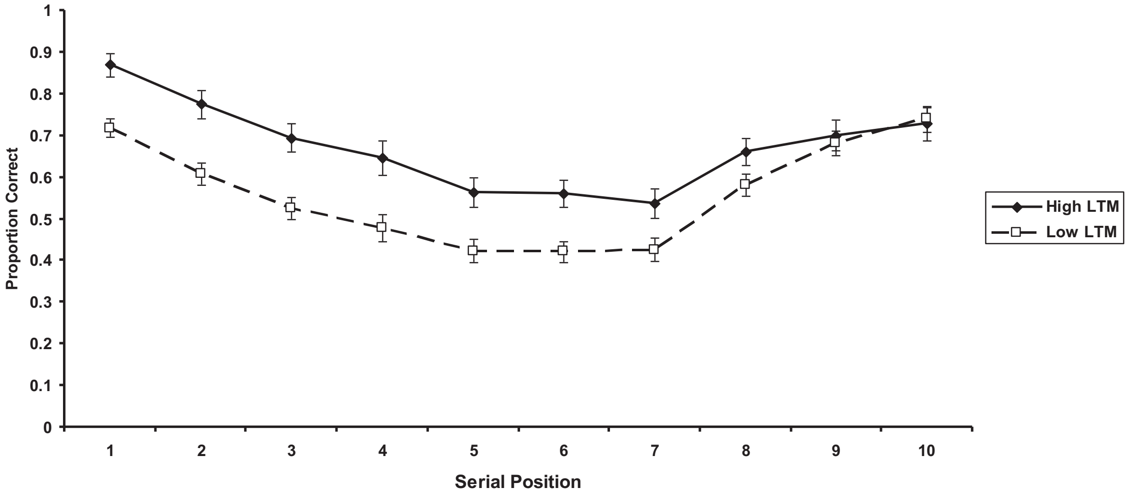

Figure 7. Proportion correct as a function of serial position for high and low long-term memory (LTM) participants for immediate free recall. Error bars reflect one standard error of the mean. Data from Unsworth et al. (2011a).

tive abilities with primacy demonstrating somewhat stronger relations than recency.

Although performance on immediate free recall is thought to rely on both WM and LTM, delayed free recall is thought to be primarily an LTM measure. As such, LTM abilities should be related to all serial positions (even recency positions) in delayed free recall. To examine this we can return to data from Unsworth and Brewer (2009, 2010a) in which participants performed a number of different LTM tasks including a fairly standard delayed free-recall task. To examine LTM abilities a LTM factor composite was formed based on all of the LTM tasks except for the delayed free-recall task with unrelated items and the two judgment of recency tasks which had a weak loading on the overall LTM factor (see above). Including LTM abilities as a covariate in analysis of covariance suggested a main effect of LTM abilities, $F(1, 174) = 97.67$, $MSE = .14$, $p < .001$, partial $\eta^2 = .36$, in which the LTM composite and delayed free recall were correlated ($r = .60$), but there was also an interaction between LTM abilities and serial position, $F(9, 1566) = 3.46$, $MSE = .04$, $p < .001$, partial $\eta^2 = .02$. As shown in Figure 8a, high and low LTM participants differed at all serial positions, but the differences were smallest for primacy items. Indeed, correlations between the LTM composite and serial position in delayed free recall were moderate for all serial positions, but slightly weaker for primacy positions (serial position 1 $r = .22$, serial position 2 $r = .19$, serial position 3 $r = .35$, serial position 4 $r = .38$, serial position 5 $r = .37$, serial position 6 $r = .48$, serial position 7 $r = .41$, serial position 8 $r = .39$, serial position 9 $r = .39$, serial position 10 $r = .42$). Thus, unlike immediate free recall, LTM abilities were related to both primacy and recency portions of the serial position curve for delayed free recall.

Although serial position curves provide a breakdown of overall accuracy on free-recall tasks, they too can be further broken down (Howard & Kahana, 1999; Kahana, Howard, & Polyn, 2008). Examining probability of first recall (PFR) provides a means of examining potential differences in how participants initiate recall. PFR refers to the number of times the first word recalled comes from a given serial position divided by the number of times the first recalled word could have come from that serial position. For instance, if a person begins recall with the last presented word nine out of 10 times, then the probability of first recall for that serial position would be .90. Prior research with immediate free recall has suggested large differences in how participants initiate recall with some participants starting recall with primacy items, some participants starting with recency items, and some splitting between primacy and recency items (Unsworth et al., 2011a; see also Healey & Kahana, 2014). In delayed free recall participants typically start recalling with primacy items (Kahana, Howard, Zaromb, & Wingfield, 2002; Unsworth, 2008). Whereas there are considerable differences in how individuals initiate recall in immediate free recall, it is less clear whether differences in recall initiation occur in delayed free recall as a function of LTM abilities. Shown in Figure 8b are PFR curves for high and low LTM participants from Unsworth and Brewer (2009, 2010a). As can be seen, the overall curves are very similar with some differences occurring at the first position. In fact, when entering LTM abilities as a covariate in an analysis of covariance there was no interaction between LTM abilities and serial position, $F(9, 1566) = 97.67$, $MSE = .02$, $p = .22$, partial $\eta^2 = .008$. Furthermore, LTM abilities did not correlate with PFR for any serial positions (all rs < 14, all ps $>$ .07). In general, these reanalyses suggest that participants typically start off recalling with primacy items in delayed free recall with little individual variability (see Kahana et al., 2002 for a similar null result in terms of aging and Spillers & Unsworth, 2011 for a null result in terms of WM abilities).

Following recall initiation, one can also examine how participants transition between items during recall. In particular, one can compute the conditional response probability as a function of lag (lag-CRP; Howard & Kahana, 1999; Kahana, 1996), which illustrates the probability that an item from serial position i + lag is recalled immediately following an item from serial position i. Prior research has found that lag-CRPs have a characteristic form such that recall of an item is generally followed by recall of nearby items with a forward bias (Howard & Kahana, 1999; Kahana, 1996; Kahana et al., 2008). This has been taken as evidence that participants rely on temporal-contextual relations during recall (Howard & Kahana, 1999; Kahana, 1996; Kahana et al., 2008, although see Hintzman, 2016 for concerns with this measure and for alternative explanations). Examining immediate free recall, Healey and Kahana (2014) found large individual differences in the form of lag-CRPs and a lag-CRP factor was found to predict overall recall levels and intelligence (Healey et al., 2014). Examining high and low WM individuals on delayed free recall, Spillers and Unsworth (2011) found that low WM individuals had reduced lag-CRPs compared with high WM individuals. Thus, these results suggest that there are individual differences in how participants transition between items during delayed free recall. Indeed, shown in Figure 8c, high LTM individuals were more likely to transition to nearby items in the forward direction than low LTM individuals. Entering LTM abilities as a covariate in an analysis of covariance suggested an interaction between LTM abilities and direction, $F(1, 174) = 11.10$, $MSE = .01$, $p = .001$, partial $\eta^2 = .06$, with LTM differences occurring in the forward direction but not the backward direction. There was also an interaction between LTM abilities and lag, $F(4, 696) = 4.59$, $MSE = .01$, $p = .001$, partial $\eta^2 = .03$, suggesting that high LTM individuals were more likely to transition to nearby items than low LTM individuals. Collectively these results suggest that LTM abilities are related to how participants dynamically recall items during free-recall tasks, with large individual differences occurring for how participants transition between items. High LTM ability individuals seem better able to organize their search of LTM via temporal-contextual cues than low LTM ability individuals, with little variation in how participants initiate retrieval from LTM.

Additional work suggests that other factors can influence individual differences in free recall. For example, the amount of study time per item has long been known to influence how many items are recalled as well as serial position curves (e.g., Wixted & McDowell, 1989). Study time can also influence individual differences in recall. For example, Shuell and Keppel (1970) had participants (fifth grade students) perform a free recall pretest. Participants scoring in the top third were considered high recall participants and participants in the bottom third were considered low recall participants. These participants then performed a free-recall task in which the words were either presented for 1 s, 2 s, or 5 s. Shuell and Keppel found that recall performance increased as study time increased, but this did not interact with group, suggesting that high and low recall participants benefited from increases

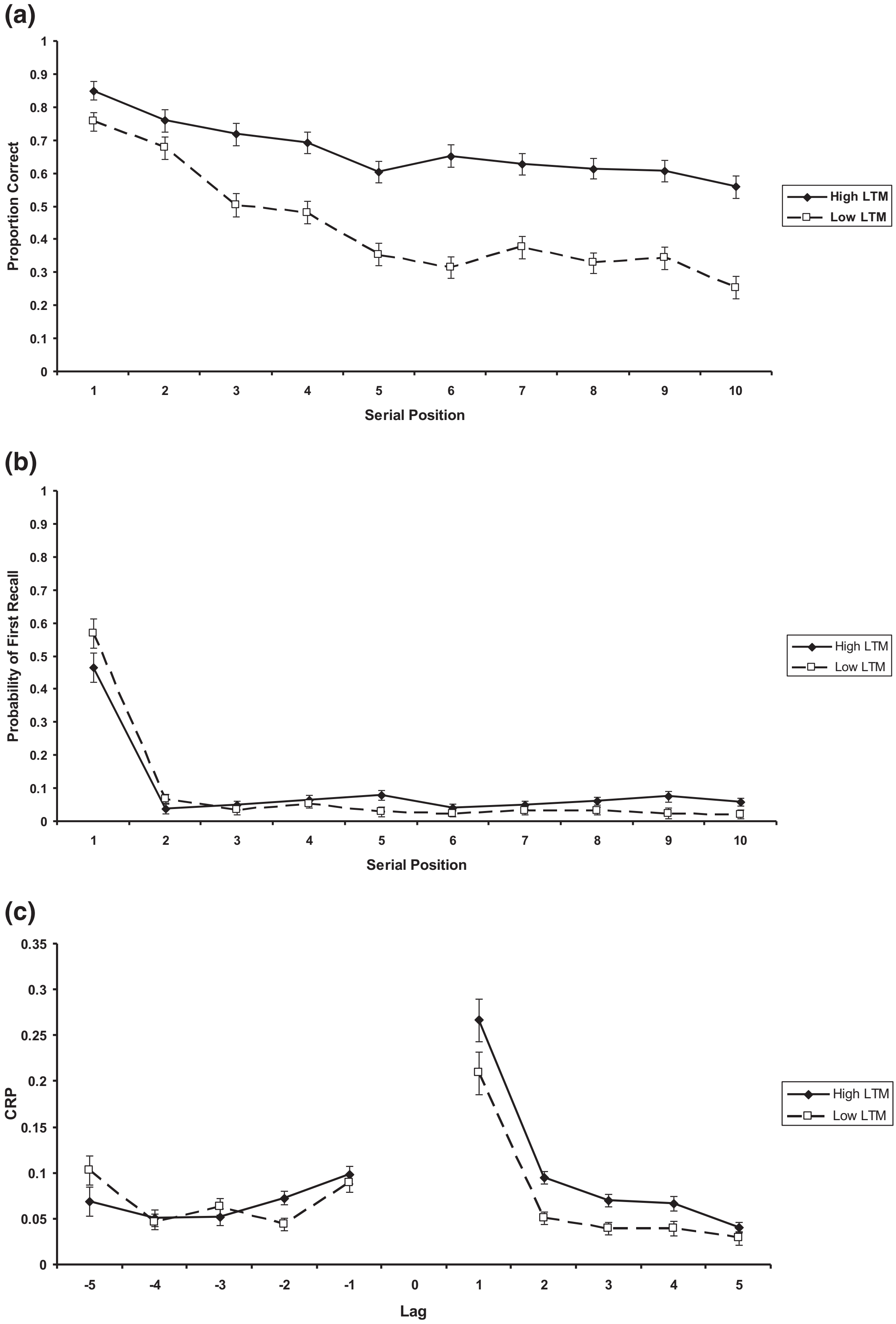

Figure 8 (*opposite*).

in study time in a similar fashion. Furthermore, they found that low recall learners in the 5-s condition recalled as many items as high recall participants in the 1-s condition. Thus, they suggested that low recall participants simply needed more time to encode the words to equate them with the high recall group. In subsequent experiments they used different study times for high and low recall participants to equate them on initial learning.

In a similar fashion, Unsworth (2016b) had participants perform three different delayed free-recall tasks with words presented for 1 s, 4 s, or participants had control over the amount of study time per word (e.g., Engle, Cantor, & Carullo, 1992; Kellas, Ashcraft, Johnson, & Needham, 1973). Unlike Shuell and Keppel (1970) a reanalysis of Unsworth (2016b) suggested an interaction between overall recall scores and study time, $F(2, 230) = 10.38$, $MSE = .14$, $p < .001$, partial $\eta^2 = .08$, such that high recall participants benefited more from increases in study time (M 1s = .63, M 4s = .85, M unlimited = .89) than low recall participants (M 1s = .33, M 4s = .46, M unlimited = .40). Furthermore, unlike Shuell and Keppel (1970) high and low recall participants were not equated in performance when presentation duration was long. Indeed, even when participants were allowed to control the timing of each word, low recall participants did not reach the same level as high recall participants in the 1s condition. This suggests that low recall participants were likely not allocating study time as efficiently as high recall participants. In fact, if we look at study time per word as a function of serial position in Figure 9a, we see that high recall participants tend to increase the amount of study time for each word across serial position, whereas low recall participants tend to decrease the amount of study time as a function of serial position, allocating most of their study time to the first word presented, $F(9, 1098) = 3.21$, $MSE = 5728931$, $p = .001$, partial $\eta^2 = .03$. These differences in study time allocation are demonstrated in differences in serial position curves for accuracy as shown in Figure 9b, $F(9, 1098) = 9.94$, $MSE = .04$, $p < .001$, partial $\eta^2 = .08$. Whereas high recall participants show high recall for all items and a relatively flat serial position curve (possibly attributable to ceiling effects), low recall participants show a more pronounced primacy effect with very low levels of recall associated with recency items. These results suggest, at least in the current data, that high recall participants benefit more from increases in study time than low recall participants, and high recall participants are better able to allocate study time to items and increase study time across items than low recall participants.

Other aspects of free recall accuracy have also been examined. For example, in a thorough review of the literature, Ozier (1980) examined individual differences in multitrial free recall in which participants are given a list of items for free recall. Following the free recall test, participants are presented with the same words (typically in a different order) and asked to recall them again across several different trials. As might be expected performance tends to increase across trials and there are large individual differences in the change in performance (Ozier, 1980). Furthermore, Ozier found that much of the variation in performance was due to variation in subjective organization (i.e., the tendency to consistently organize recall the same way across trials) and subjective organization was related to a various LTM measures, but was not related to WM, gF, gC, or to effects of presentation duration, levels of processing, lag, or rote rehearsal. Subsequent research has similarly suggested that there are large individual differences in multitrial free recall, which are related to other cognitive abilities, but there is inconsistent evidence suggesting that subjective organization is related to other cognitive abilities (Harrison, 2014; Krueger & Salthouse, 2011; Miller & Unsworth, 2018).

Although accuracy is the primary measure of importance on free-recall tasks, other measures are also informative. For example, the type and frequency of different errors can be examined (see also below on False Memory). In most studies of free recall, intrusion errors (items not presented on the current list) are typically not examined given the rarity with which they occur. Yet when they are examined a number of interesting and systematic findings emerge. Intrusion errors can be broken down into two types: previous-list and extralist intrusions. Previous-list intrusions (PLIs) represent words that were not presented on the current list that participants are trying to remember, but were presented on previous lists. Extralist intrusions (ELIs) represent words that were not presented on any of the lists. PLIs predominantly come from the immediately preceding list, and the recency gradient for PLIs tends to fall off monotonically for lists further back (Bennett, 1975; Murdock, 1974; Unsworth, Brewer, & Spillers, 2010; Unsworth & Engle, 2007; Zaromb et al., 2006). PLIs also tend to come predominantly from primacy and recency positions on the lists they were presented on (Unsworth, 2008; Unsworth et al., 2010). This is likely because PLIs typically are words that were initially recalled correctly on their respective lists. Very few unrecalled items appear as PLIs in later lists. Furthermore, ELIs tend to be either semantically or phonologically related to one of the target words in the current list (e.g., Craik, 1968; see also Watson, Balota, & Sergent-Marshall, 2001; Zaromb et al., 2006). In terms of individual differences, prior research has found that PLIs and ELIs are strongly correlated and typically load onto the same intrusion factor (Jonker, 2016; Unsworth, 2009b, 2016b; Unsworth & Brewer, 2010a). This latent intrusion factor has been shown to be strongly related to overall recall abilities (Jonker, 2016; Unsworth, 2009b, 2016b: Unsworth & Brewer, 2010a) and false alarms in recognition memory tasks (Jonker, 2016; see also Healey & Kahana, 2016). Interestingly, although low LTM individuals emit more intrusions than high LTM individuals, the source of these intrusions tend to be the same. That is, the PLI recency effect does not differ as a function of LTM abilities, $F(4, 444) = 1.79$, $MSE = .007$, $p = .13$, partial $\eta^2 = .02$. For example, as shown in Figure 10, high and low LTM ability individuals have similar PLI recency curves. Similar results have been found when examining

Figure 8 (*opposite*). (a) Proportion correct as a function of serial position for high and low long-term memory (LTM) participants for delayed free recall. (b) Probability of first recall as a function of serial position for high and low long-term memory (LTM) participants for delayed free recall. (c) Conditional response probability functions for forward and backward transitions per list as a function of lag for high and low long-term memory (LTM) participants for delayed free recall. Error bars reflect one standard error of the mean. Data from Unsworth and Brewer (2009, 2010a).

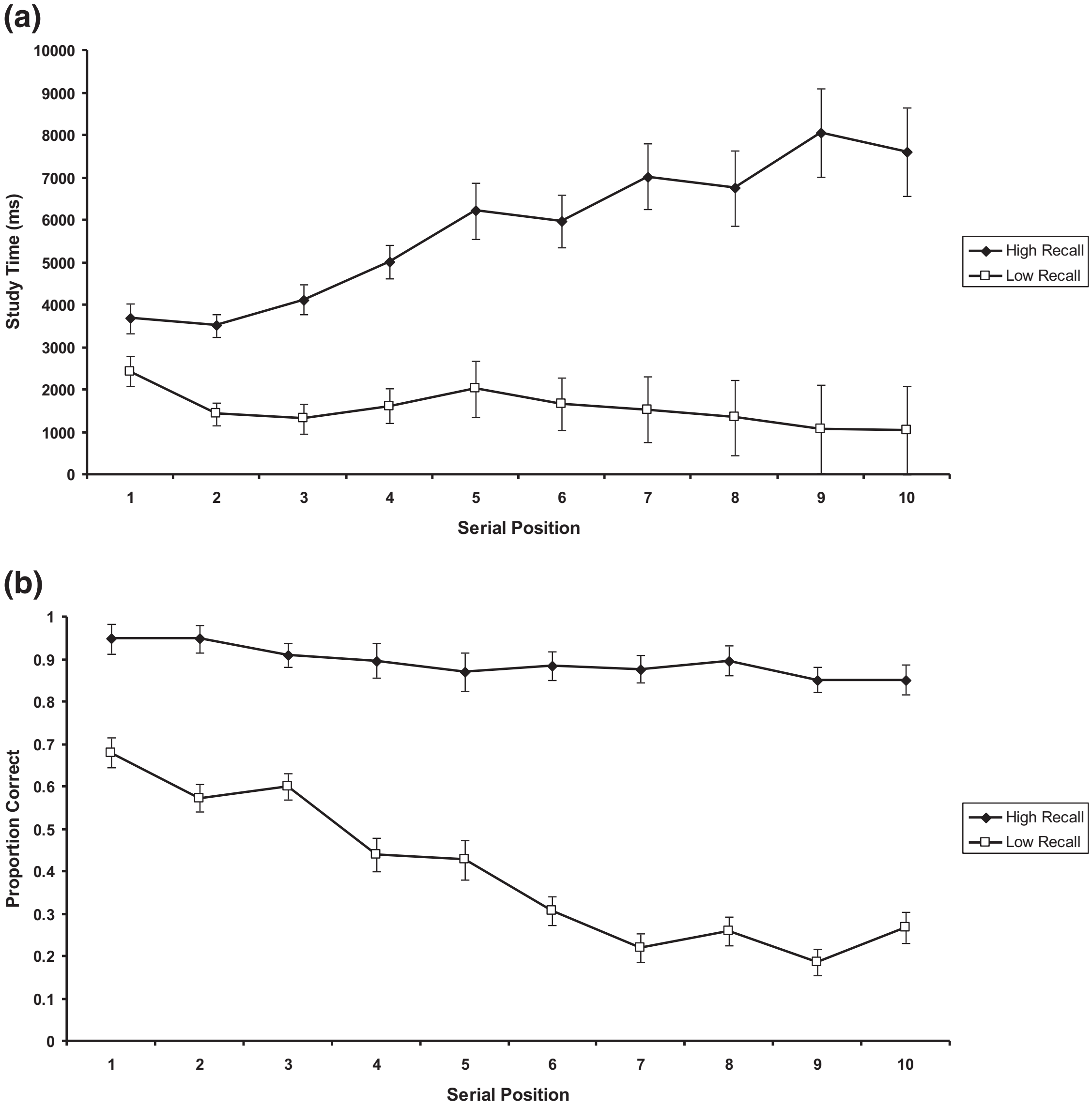

Figure 9. (a) Study time as a function of serial position for high and low recall participants. (b) Proportion correct as a function of serial position for high and low recall participants. Error bars reflect one standard error of the mean. Data from Unsworth (2016b).

PLI recency curves for older and younger adults (Zaromb et al., 2006) and for high and low WM individuals (Unsworth & Engle, 2007). In all cases, the lower ability group tends to recall more intrusions, but where the intrusions come from is similar.

Individual differences in intrusions are related not only to overall recall levels, but also to latent factors of source monitoring, WM, judgments of recency, gF, and gC (Unsworth, 2009b, 2010b; Unsworth & Brewer, 2010a). Examining mediation models suggests that much of the relation between individual differences in intrusion errors and other cognitive constructs is attributable to variation in source monitoring abilities such that individuals with better source monitoring abilities are less likely to emit intrusions during free recall (Unsworth & Brewer, 2010a; see also Rose, 2013). One way to examine variation in monitoring abilities during free recall is to use a variant of externalized (or uninhibited) free recall in which participants are instructed to recall all of the words from the current list and to recall any words that come to mind during the recall phase, even if they know that the word is not from the current list (Bousfield & Rosner, 1970; Kahana, Dolan, Sauder, & Wingfield, 2005; Roediger & Payne, 1985; Unsworth et al., 2010). Furthermore, to examine editing processes within externalized free recall, Kahana et al. (2005) instructed participants to press a key immediately after any response that the participant knew was incorrect and found that older adults emitted more intrusions than younger adults and older adults were also less likely to recognize their intrusions as errors. Similarly, Unsworth and Brewer (2010b) found that low WM individuals emitted more intrusions (especially PLIs) than high WM individuals, and low

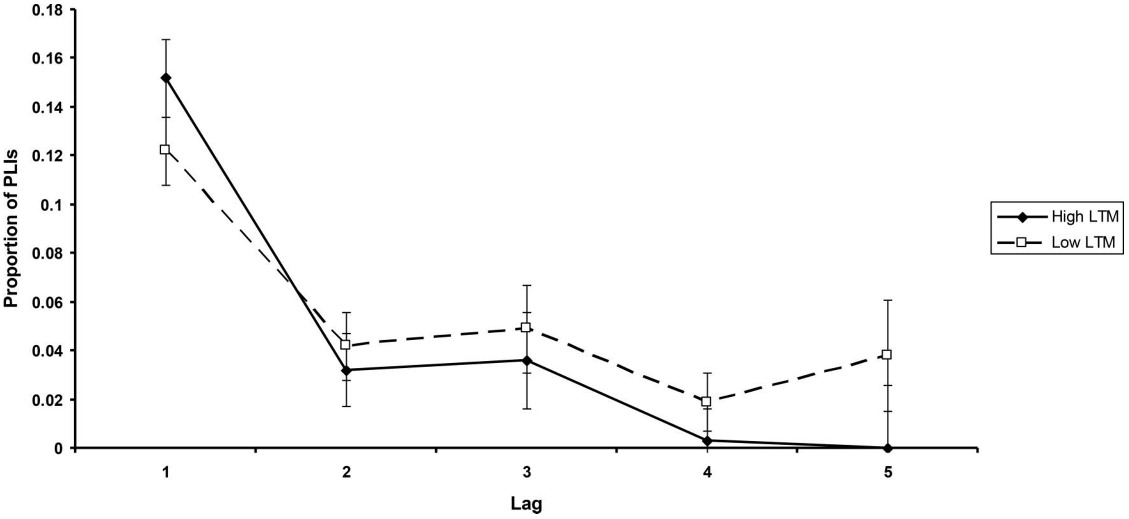

Figure 10. Proportion of previous-list intrusions (PLIs) as a function of lag (list) for high and low long-term memory (LTM) ability individuals. Error bars reflect one standard error of the mean. Data from Unsworth (2009b).

WM individuals were less likely to correctly recognize their intrusions as errors compared with high WM individuals. Unsworth and Brewer (2010a) used the same task in examining individual differences in intrusion errors. Reanalyzing that data suggests that the ability to correctly recognize intrusions as errors was related to overall LTM abilities ($r = .24$) with high LTM individuals correctly classifying 72% ($SD = 32$) of their intrusions, whereas low LTM ability individuals only correctly classified 51% ($SD = 36$) of their intrusions as errors. Thus, low LTM individuals are more likely to emit intrusions than high LTM ability individuals and this is partially due to individual differences in source monitoring abilities.

The work reviewed thus far has focused on probability of correct recall and intrusion errors. However, an examination of recall latency can also be informative in terms of better understanding how participants search for target items in free-recall tasks. Recall latency refers to the time point during the recall period when any given item is recalled, and mean recall latency is simply the average time it takes to recall items. For instance, if items are recalled 5 s, 10 s, and 15 s into the recall period, mean recall latency would be 10 s. Prior work has suggested that recall latency distributions provide important information on the dynamics of free recall. (Bousfield & Sedgewick, 1944; Indow & Togano, 1970; McGill, 1963; Rohrer & Wixted, 1994; Roediger, Stellon, & Tulving, 1977; Wixted & Rohrer, 1994). Whereas probability of correct recall gives an estimate of the number of items that were encoded and subsequently retrieved, these items can be recalled either quickly or slowly and this information is captured by recall latency. That is, two participants might recall the same number of items, but how quickly they recall these items might differ for theoretically important reasons.

Overall recall latency distributions are consistent with search models of free recall (Rohrer, 1996; Shiffrin, 1970a). In these models it is assumed that during recall a retrieval cue activates a subset of representations in memory (search set) that are related to the cue in some fashion and representations are sampled (with replacement) from the search set based on a relative strength rule (Raaijmakers & Shiffrin, 1980; Rohrer, 1996; Shiffrin, 1970a). Items whose strength exceeds some critical threshold will be recovered and can be recalled, whereas weak items that do not exceed the threshold will not be recovered (Rohrer, 1996). In these search models probability of correct recall reflects the number of recoverable items in the search set whereas recall latency reflects the number of items within the search. The larger the search set the longer on average it will take to recall any given item (e.g., Rohrer, 1996; Rohrer & Wixted, 1994; Unsworth, 2015; Wixted & Rohrer, 1993, 1994).

Examining individual differences in search dynamics, Unsworth (2009b) found that recall latency measured across three different free-recall tasks correlated and formed a latent recall latency factor and this factor was negatively correlated with overall recall accuracy, WM, and gF but positively correlated with an intrusion factor (see also Unsworth, 2016b). Thus, those individuals who recalled items the slowest tended to have lower LTM, WM, and gF abilities and tended to recall the most intrusions. Furthermore, recall accuracy and recall latency both accounted for shared and unique variance in WM and gF, suggesting that they were not simply redundant measures. These results are consistent with the notion that lower ability individuals tend to have larger search sets than high ability individuals. That is, low LTM ability individuals tend to rely on noisy temporal-context cues which activate not only items for the current list, but also items from the prior lists. High LTM ability individuals, however, are better able to restrict their search to the current list of items ensuring that more correct items are recalled (and less intrusions) resulting in overall shorter recall latencies (see also Unsworth, 2016b).

Although the overall correlation between abilities and recall latency are consistent with differences in search set size, the results are more complicated. Specifically, utilizing cluster analysis Unsworth (2009b) found that there were actually four subgroups of participants in the data. One subgroup was composed of high ability participants who recalled the most items and tended to recall them quickly. Another subgroup was composed of low ability participants who recalled fewer items than the high ability group and recalled those items at a much slower rate. This group is consistent with the notion that low ability individuals have larger search sets than high ability individuals. A third subgroup was composed of participants who recalled fewer items than the high ability group, but actually recalled their items at somewhat quicker rate than the high ability group. This group is consistent with the idea that some lower ability individuals actually have smaller search sets than high ability individuals. This could be due to difference in basic encoding abilities (e.g., differences in rehearsal, elaboration, or binding) in which some items are not properly encoded or it could be due to fewer resources being available to activate and retrieve the desired items during recall. Finally, a fourth subgroup recalled fewer items than the high ability group, but recalled their items at the same rate as the high ability group. This group also emitted the largest number of intrusions errors and it was suggested that this group had specific deficits in source monitoring abilities.

To see whether these results generalize, data from Unsworth and Brewer (2009, 2010a) were reanalyzed. Specifically, a two-step cluster analysis in SPSS was done on overall recall accuracy and recall latency for delayed free recall. Consistent with Unsworth (2009b) four subgroups of participants were identified. Shown in Figure 11 are the cumulative recall curves for the four subgroups. As can be seen, the first group (37% of participants) recalled the most items and recalled those items at a fairly fast rate (labeled High Recall). The second group (29% of participants) recalled fewer items than the high recall group, but recalled their items at a much faster rate (labeled Fast). The third group (15% of participants) recalled fewer items than the High Recall group (but the same as the Fast group), and recalled their items at the slowest rate (labeled Slow). Finally, the last group of participants (19%) recalled fewer items than the High Recall group (but about the same as the Fast and Slow groups), but this group recalled their items at the same rate as the High Recall group (labeled Same). As suggested above, theoretically the Slow group consists of participants with larger than normal search sets, whereas the Fast group consists of participants with smaller than normal search sets. The Same group consists of individuals with roughly the same search set size as the High Recall group, but this group have fewer recoverable (i.e., strong) items within their search sets. Thus, there are clear differences in not only how many items one can recall, but also how quickly they recall those items, and these are not redundant measures. Examining recall latency in addition to recall accuracy will be important for delineating individual differences in LTM encoding and search abilities.

Collectively, prior research and reanalyses of prior research suggest that there are individual differences in various aspects of free recall. Recent research has demonstrated that many of these different aspects of free recall are correlated and account for a large portion of the variance in free recall. For example, Unsworth (2016b) found that individual differences in study time allocation, strategy use (see below), intrusion errors, and interresponse times all uniquely predicted recall accuracy accounting for 89% of the variance in a latent free recall factor. Furthermore, many of these different free recall measures have been shown to correlate with aspects of intelligence (in particular gF). Better understanding individual variation in how participants encode and retrieve items in free-recall tasks will be important for understanding individual differences in LTM abilities more broadly.

Paired Associates

Variation in paired associates recall has also been extensively examined. In paired associates recall participants are presented with pairs of items during encoding (Pen-Glass) and at test they are presented with the cue (Pen-???) and must recall the item that was paired with it (Glass). As noted previously, paired associates tasks tend to correlate well with one another and form a general paired associates factor that is related to other LTM factors. Furthermore, paired-associates learning has been shown to predict school grades

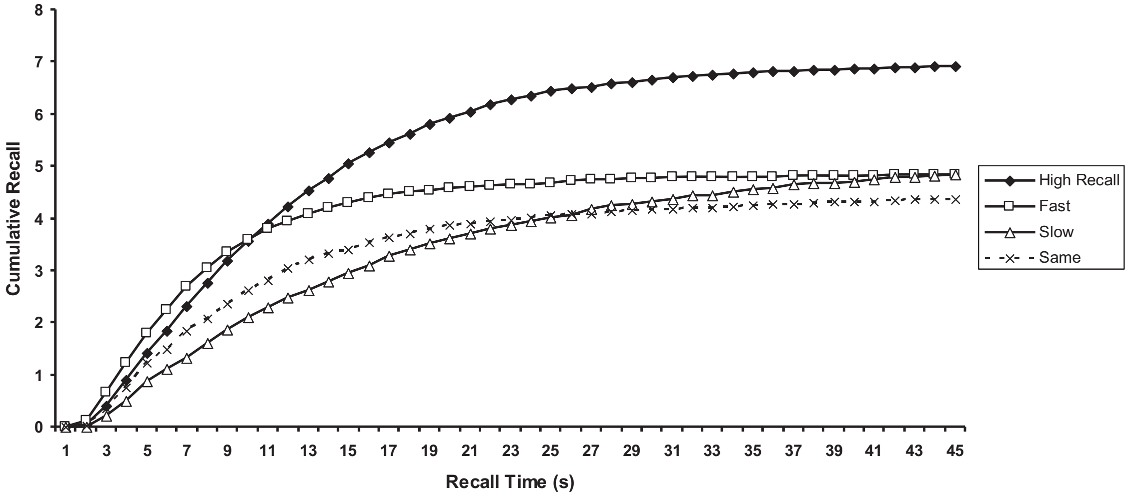

Figure 11. Cumulative recall curves as a function of recall time and subgroup. High Recall = high recall group; Fast = fast rate of recall group; Slow = slow rate of recall group; Same = same rate of recall group. See text for details. Data from Unsworth and Brewer (2009, 2010a).

(Stevenson, Hale, Klein, & Miller, 1968) and foreign language learning (Carroll, 1962). Early research examining individual differences in paired-associates learning primarily examined two related concepts: (1) Do differences in association ability predict individual differences in paired associates recall? (2) Do differences in speed of learning relate to paired associates recall and does this change as a function of the meaningfulness of the material? In terms of the first question, Mandler and Huttenlocher (1956) found a positive correlation between the ability to produce associates and paired associates recall. Specifically, participants were given nonsense syllables (e.g., ZUV) and asked to generate as many possible associates to the nonsense syllable as possible in 30 s (i.e., associational fluency). Participants also performed a paired associates task with pairs of nonsense syllables (e.g., LIR-WAT) that were not used in the associational fluency task. Mandler and Huttenlocher found that individuals who could generate more associates on the fluency task tended to do better on the paired associates task (see also Dean & Ley, 1977; Ley & Dean, 1976 for similar results in free recall). Greeno (1965) followed up on these results and found that associational fluency from both words and nonsense syllables predicted paired associates recall suggesting that individual differences in association abilities are strong predictors of performance on paired associates tasks. Similarly, Cieutat (1963) found that paired associates recall was predicted by verbal abilities as measured by college entrance exams. Like the results from Mandler and Huttenlocher (1956) and Greeno (1965), Cieutat (1963) suggested that “a general verbal ability, i.e., an ability to employ the language correctly, is associated with verbal learning ability” (p. 277).

Related to these findings and regarding the second question, Noble and McNeely (1957) found that the rate of learning is positively correlated with the meaningfulness (associational fluency) of the pairs. Furthermore, they found that this interacts with overall abilities such that slow learners seemed to benefit more from meaningful pairs than fast learners. Cieutat, Stockwell, and Noble (1958) also found that fast and slow learners differ in paired associate recall and this interacted with the meaningfulness of the stimuli. When the materials were particularly difficult (low meaningfulness) fast and slow learners diverged in their performance. However, when the material was easier (high meaningfulness) fast and slow learners converged in their performance. Carroll and Burke (1965) qualified these results somewhat by showing that fast and slow learners differed only when the material was of intermediate difficulty (e.g., low frequency words). When given easy (high frequency words) or difficult (low meaningfulness nonsense syllables) material, fast and slow learners performed similarly. Thus, early results suggested that individual differences in paired-associates learning were attributable, in part, to differences in association abilities and fast and slow learners differ as a function of the meaningfulness of the material.

More recent research has corroborated these results and shown that they are largely linked. For example, Wang (1983) examined fast and slow learners and found that fast learners generated more associations (elaborators) than slow learners during early learning. However, with more acquisition trials, slow learners began to catch up to fast learners in the number of associations they were able to generate. Furthermore, Wang found that fast learners used more associates that were related to the cue or related to both the cue and the target than slow learners. Slow learners, however, were more likely to generate associates that were linked to the target item or were more idiosyncratic. Wang suggested that individual differences in paired-associates learning were driven by both the ability/speed to generate associates and the extent to which those associates were related to the cue, the target, or both.

Research by Kyllonen, Tirre, and colleagues (Kyllonen & Tirre, 1988; Kyllonen, Tirre, & Christal, 1991; Tirre, 1991) has also examined variation in paired associates recall abilities. Kyllonen and Tirre (1988) examined paired-associates learning in a large sample ($N = 685$) of Air Force recruits and found that fast learners performed better than slow learners on the paired associates task and performed better on a battery of LTM tasks (see also Zerr et al., 2018). Kyllonen and Tirre suggested that variation in paired-associates learning was attributable, in part, to a general associative learning proficiency, and was not simply attributable to idiosyncratic task factors. Further examination of the relations suggested that the overall LTM factor was predicted by both gF and gC (but not by WM). This factor in turn predicted overall learning speed. The finding that gC (general knowledge) strongly predicted unique variance in the LTM factors and was related to paired-associates learning suggested that some variation in paired associates is likely attributable to differences in the ability to use general knowledge to generate associative links between the pairs.

Tirre (1991) reanalyzed some of his prior data and found that paired associates was predicted by gF and gC as well as self-assessments of learning. In a follow up experiment with $N = 714$ Air Force recruits, participants performed a paired associates task with different instruction conditions (Control = no instructions; Semantic Elaboration = instructed to create words out of the CVCs and to create sentences combining the words; Interactive Imagery = instructed to create words out of the CVCs and to generate an image to go with the words). Tirre found that WM, gF, gC, strategy instruction, and learning strategies all accounted for unique variance in performance on the paired associates task (accounting for roughly 68% of the variance).

In a related study, Kyllonen et al. (1991) examined the extent to which different cognitive abilities such as general knowledge and processing speed would contribute to individual differences in paired associates. In their Experiment 1, Air Force recruits ($N = 396$) performed a paired associates task in which the study time per pair was either .5 s or 8 s. Kyllonen et al. found that gC predicted overall paired associates recall, and this tended to increase with greater study time. Processing speed, however, only predicted paired associates recall with limited study time. This overall pattern of results was replicated in their subsequent experiments with additionally large sample sizes (N’s ranging from 215–708). Furthermore, Kyllonen et al. found that these results held regardless of the type of stimuli (words versus CVCs), regardless of whether study time was mixed or blocked, and regardless of whether participants were trained to use a strategy or not. Overall these results suggest that with greater study time, high gC individuals were better able to use their general knowledge to generate elaborations and links for the pairs than low gC individuals. With very short study times, processing speed was also critically important for determining variation in paired associates recall. Like prior research, these results suggest the importance of general knowledge and other cognitive abilities in determining variation in paired associates recall.

Additional research has further examined relations between paired associates and other cognitive abilities. For example, Hakstian and Cattell (1974) found that a paired associates factor correlated with aspects of verbal knowledge/gC (r = .30), and inductive reasoning/gF (r = .44). Hundal and Horn (1977) found that a memory factor composed of paired associates tasks correlated with both gF (r = .44) and gC (r = .69) factors. Reanalyzing data from Underwood et al. (1978) suggests that the paired associates factor is correlated with gC (r = .28). Likewise, reanalyzing data from Unsworth and Brewer (2009, 2010a) suggests that paired associates recall is correlated with WM (r = .34), gF (r = .53), and gC (r = .22). Combined with the work of Kyllonen, Tirre, and Christal (Kyllonen & Tirre, 1988; Kyllonen et al., 1991; Tirre, 1991), it is clear that paired associates recall is moderately related with other cognitive abilities.

More recent research has further demonstrated that more complex paired associates tasks seem to correlate more strongly with gF than simpler paired associates tasks. Williams and Pearlberg (2006) had participants perform fairly standard paired associates and free-recall tasks along with Raven Advanced Progressive Matrices. Participants also performed a three-term contingency paired associates task. In this task, the cue word was paired with three different targets. During learning, each pairing was learned and at recall the cue word was presented along with a marker indicating that participants needed to recall the target response associated with the cue. Williams and Pearlberg found that the standard paired associates and free-recall tasks did not correlate with Ravens, but the three-term contingency task did (r = .52). This overall pattern was replicated in a second experiment in which the three-term contingency task was related to Ravens, but not to measures of WM or processing speed. Williams and Pearlberg claimed to have found novel evidence that paired-associates learning is related to gF (although see above). Following up on these findings, Tamez, Myerson, and Hale (2008) found that both verbal and nonverbal three-term contingency tasks predicted Ravens, and both were related to measures of WM. Using latent variable techniques, Kaufman, DeYoung, Gray, Brown, and Macintosh (2009) found that a standard paired associates task and the three-term contingency task were correlated and loaded on the same factor and this factor was related to gF (r = .45), WM (r = .22), and processing speed (r = .17). This line of research suggests that a fairly complex and difficult paired associates task in which the cue is associated with multiple targets is consistently related with gF and WM (see also Lilienthal, Tamez, Myerson, & Hale, 2013; Tamez, Myerson, & Hale, 2012). This relation may be attributable to a combination of factors, including increasing the need to establish and maintain correct cue-target bindings at encoding as well as deal with retrieval competition and interference at recall (Lilienthal et al., 2013).

Examination of error responses in addition to overall accuracy can also be informative. In paired associates recall there are three primary types of errors that participants can make. Participants can make omissions where no response was given during recall or they can make an intrusion. Intrusions include intralist intrusions where an item presented in the experiment was incorrectly recalled and extralist intrusions where an item that was not presented was incorrectly recalled. Prior research has found that intralist and extralist intrusions are strongly correlated and load on the same factor (Unsworth & Brewer, 2010a). Omissions and intrusions tend to be negatively correlated, and both are negatively related to overall levels of performance (Unsworth, 2009c). Furthermore, reanalyzing data from Unsworth and Brewer (2009, 2010a) suggests that a latent intrusion factor is related to WM (r = −.21), gF (r = −.24), gC (r = −.20), item recognition (r = −.17), source recognition (r = −.47), and free recall (r = −.25) factors. Interestingly omissions were related to gC (r = .22) and free recall (r = −.24), but not to any of the other factors (WM = .05, gF = .11, item recognition = −.01, source recognition = .16). Thus, much of the variation in errors that are made on paired associates tasks are due to intrusion errors, and the strongest predictor of intrusions tended to be source monitoring abilities (similar to what is seen with free recall).

Recall latency can also be examined and prior research has suggested that there are important individual differences in the speed with which participants can recall information. For example, Unsworth (2009c) found that recall latency associated with correct items was negatively correlated with overall recall levels and WM, and was positively correlated with omission and intrusion errors. Similar to free recall these results suggest that low ability individuals take longer to retrieve correct items than high ability individuals. One can also examine recall latencies associated with error (intrusions) responses. Prior research has suggested that error recall latencies provide an index of the willingness to continue searching (MacLeod & Nelson, 1984; Millward, 1964). Kyllonen et al. (1991) found a positive correlation between error recall latency and gC and suggested that high knowledge participants are willing to search longer than low knowledge participants when they do not immediately know the answer. However, other research suggests that error recall latencies are not related with overall accuracy levels in paired associates or with omissions and intrusions (Unsworth, 2009c). Thus, more research is needed to better examine the notion that error recall latencies and variation in the willingness to continue searching for correct items in paired associates recall is related to other cognitive abilities (see also Dougherty, & Harbison, 2007 for similar analyses in free recall).

Individual differences in paired associates recall are attributable, in part, to variation in the ability to create and maintain associative links between cue and target pairs. This ability seems partially attributable to gC in which higher knowledge participants have more information at their disposal to create the associative links than low knowledge participants. Overall, it is clear that there are large and important differences in paired associates recall, but it is also clear that much research remains to be done to better elucidate the underlying sources of this variation.

Recognition

Prior research has suggested that there are important individual differences in recognition memory performance.[3] In an early discussion of individual differences in recognition, Hollingworth (1913) noted “individual differences in recognition are apparent in any experiment with this process” (p. 542). Furthermore, as noted

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[3] There are also robust individual differences in face recognition abilities (e.g., Bate et al., 2018; Duchaine & Nakayama, 2006; Fysh, 2018) and these are critically important for issues such as eyewitness identification (see thematic series on Individual Differences in Face Perception and Person Recognition in *Cognitive Research: Principles and Implications*).

above, recognition memory tasks have long been used in different factor analytic studies, demonstrating that these tasks tend to load with other LTM tasks. When several recognition memory tasks are administered, these tasks all tend to load onto the same factor and this factor correlates with other LTM factors. In a typical recognition memory task participants are presented with a list of items (words, pictures, etc.) one at a time during study. At test, participants are presented with a mix of studied and new items. Participants are required to respond "old" if the item was previously presented during study and "new" if the item is new. In most prior factor analytic studies, performance was simply overall accuracy on the test. Although overall accuracy is informative, it may be more informative to examine individual differences in the various responses participants can make based on signal detection theory (e.g., MacMillan & Creelman, 1991). Specifically, in old-new recognition there are four types of responses, hits (an old item called old), false alarms (a new item called old), misses (an old item called new), and correct rejections (a new item called new). In terms of individual differences, examining hits and false alarms is important because it is possible that two individuals have the same overall accuracy, but differ in how they achieved that accuracy. For example, one individual might have a hit rate of .80 and a false alarm rate of .20 for an overall accuracy of 80%. Another individual may similarly have an overall accuracy of 80%, but with a hit rate of .70 and false alarm rate of .10. Thus, the individuals would not differ in overall accuracy, but would differ in both hits and false alarms. Realizing these issues, a number of studies have examined correlations for hits and false alarms and their relations with other LTM and cognitive ability measures. Across studies, hits and false alarms tend to be negatively correlated (Bartlett, Shastri, Abdi, & Neville-Smith, 2009; Jonker, 2016; Lilienthal, Rose, Tamez, Myerson, & Hale, 2015; although see Ben-Artzi & Raveh, 2016 for a positive correlation). Furthermore, hits and false alarms tend to load on separate factors and differentially correlate with other individual differences measures. For example, Bartlett et al. (2009) found that hits and false alarms on a recognition memory task with faces loaded on separate factors. Jonker (2016) found that hits and false alarms loaded on separate factors and both were related to intrusion errors. Lilienthal et al. (2015) found that hits were related to WM, but false alarms were not. Ben-Artzi and Raveh (2016) found that hits and false alarms were differentially related to aspects of perfectionism. In a large study examining false recognition, Salthouse and Siedlecki (2007) found that corrected hits (i.e., hits – false alarms) were correlated with a separate LTM latent variable and weakly related with gC. In another study of false recognition McCabe, Roediger, McDaniel, and Balota (2009) found that hits were related to an LTM composite, but not an executive functioning composite. False alarms, however, were related to both LTM and executive functioning. Thus, across different studies there is evidence that hits and false alarms load on separate factors and are differentially related to different cognitive abilities.

To further assess this, recognition memory data from Unsworth and Brewer (2009, 2010a) were reanalyzed and hits and false alarms were computed for each task. Hits were related across tasks ($r = .17$) as were false alarms ($r = .45$). Next a confirmatory factor analysis was specified in which hits loaded on one factor and false alarms on another. These factors were allowed to correlate with each other and with other ability factors. The overall fit of the model was acceptable, $\chi^2(159) = 204.19$, $p < .01$, RMSEA = .04, NNFI = .95, CFI = .96, SRMR = .06. Hits and false alarms were negatively correlated ($r = -.64$). As shown in Table 3, hits were strongly related to the other LTM measures and to the cognitive ability measures and false alarms demonstrated overall much weaker relations with the cognitive ability measures. Thus, similar to prior research hits and false alarms were shown to be differentially related to other LTM measures and to other cognitive ability measures.

In addition to examining overall hit and false alarm rates, research has relied on signal detection measures to examine individual differences in item recognition. In signal detection theory it is assumed that recognition decisions are based on the strength of a memory signal in relation to a decision criterion. Typically it is assumed that there are two distributions, with one representing targets and the other representing lures. There is also a decision criterion such that an item that generates a memory strength exceeding the criterion is considered old and items whose strength do not exceed the criterion are considered new. Within signal detection theory there are two important measures: discriminability and response bias. Discriminability is measured by the distance (d') between the means of the distributions for targets and lures. Response bias, however, refers to where the criterion is placed. In terms of individual differences, both measures are likely important given that differences in hits and false alarms can arise because of changes in discriminability or changes in response bias. Because of how d' is calculated, it will tend to correlate highly with hits and false alarms, and with overall accuracy. As such, there have been relatively few studies that have examined correlations between d' from item recognition tasks and other cognitive abilities. For example, Oberauer (2005) found that a d' factor was related to a WM factor (see also Lilienthal et al., 2015). McCabe et al. (2009) found that d' was positively related to both executive functioning and LTM while Ben-Artzi and Raveh (2016) found that d' was negatively related to perfectionist concerns. Similar to what was seen with hits, individual differences in d' tend to correlate with other LTM measures and with other cognitive ability measures. Data from Unsworth and Brewer (2009, 2010a) were reanalyzed to see whether d' across different tasks correlate and load on the same factor and the extent to which this factor is related to other cognitive ability measures. The d's were correlated ($r = .41$), so a confirmatory factor analysis was specified in which d' from the

Table 3
Latent Factor Correlations Between Item Recognition Measures and Other Cognitive Abilities

	Item recognition measures			
Factor	Hits	False alarms	d'	c
WM	.49	−.30	.40	**.03**
gF	.86	−.31	.55	**−.13**
gC	.38	**−.17**	.22	**−.06**
Source	.99	−.79	.93	**.07**
FR	.77	−.34	.62	**−.13**
PA	.88	−.33	.65	−.22

Note. WM = working memory; FR = free recall ; PA = paired associates; gF = general fluid intelligence; gC = general crystallized intelligence. Bold values are not significant at $p < .05$. c is based on the item recognition memory task with words only. See text for details.

two item recognition tasks loaded onto one factor and this factor was allowed to correlate with latent factors the other cognitive ability measures. The overall fit of the model was acceptable, $\chi^2(131) = 166.32$, $p < .01$, RMSEA = .04, NNFI = .96, CFI = .97, SRMR = .06. In Table 3 are the resulting correlations with the other factors showing that *d*′ was strongly related to the other LTM measures and moderately related to the other cognitive ability measures (similar to what was seen with hits). Thus, individuals differ in meaningful ways in terms of memory discriminability as assessed on item recognition tasks.

Although only few studies have examined discriminability, more recent research has examined individual differences in response bias. Individuals with a liberal response bias are likely to say yes resulting in high hit and false alarm rates, whereas individuals with a more conservative response bias are more likely to say no leading to lowered false alarm and hit rates. Thus, individual differences in response bias could be an important contributor to individual differences in item recognition. Kantner and Lindsay (2012) conducted four experiments (with *N*s ranging from 31–50) in which participants performed a number of item recognition tasks as well as additional measures. Bias was computed in multiple ways and Kantner and Lindsay found that response bias was generally reliable within a task, across tasks, within a session, and across sessions. Furthermore, response bias demonstrated inconsistent relates with intrusions, and was generally not related to a measure of general knowledge. Kantner and Lindsay (2014) again found response bias to be reliable and found that it related weakly to some measures (such as go/no-go accuracy and eye witness identification), but not to others (such as go/no-go reaction time [RT], need for cognition, or the BIS/BAS scale). Additional research has suggested that response bias is related to overall memory abilities (hits and *d*′) in the tasks that it estimated from (Ben-Artzi & Raveh, 2016; Jonker, 2016; Zhu, Chen, Loftus, Lin, & Dong, 2013), but response bias tends to demonstrate much weaker relations with the same metrics when estimated with different tasks (Jonker, 2016; Zhu et al., 2013). Jonker (2016) found that a response bias factor could be formed based off of three measures and this factor was related to memory abilities (primarily based on hits) and intrusions errors. Chen (2017) found that response bias was reliable, and that overall memory ability (*d*′) correlated with cognitive abilities (SAT/ACT scores, go/no-go performance, and task-switching), but response bias did not correlate with any of the cognitive ability measures. Thus, prior research suggests that there are reliable individual differences in response bias measured from item recognition tasks, but the validity of response bias is less clear. Although response bias tends to correlate with other measures (hits, false alarms, *d*′) these relations are typically from the same task and are likely partially due to task dependencies. Relations between response bias and other measures tend to be much weaker and inconsistent.

To examine this further, data from Unsworth and Brewer (2009, 2010a) were reanalyzed and response bias (*c*) was examined. Unlike *d*′, *c* was not correlated across the two tasks ($r = .04$). This was likely partially due to the fact that performance on the item recognition task with pictures with high (*M* proportion correct = .96, *SD* = .05). Because of this, and because response bias from the item recognition task with words had somewhat larger correlations with other measures, this measure was entered into a confirmatory factor analysis as a manifest variable and was allowed to correlate with latent factors for the other cognitive ability measures. The overall fit of the model was acceptable, $\chi^2(143) = 185.57$, $p < .01$, RMSEA = .04, NNFI = .95, CFI = .97, SRMR = .06. As seen in Table 3, response bias was weakly related to the other measures with the only significant relation being with paired associates recall. Thus, again it does not seem like response bias is consistently related to other cognitive abilities. Response bias can also be estimated by examining false alarm rates. As shown in Table 3, false alarms were related to all of the measures. However, these relations could be partially due to shared variance with hits given that hits and false alarms were correlated (see supplemental materials for a model examining this notion). Thus, although it seems like there are reliable individual differences in response bias; it remains unclear whether this variation related to other cognitive abilities.

Recent research has also examined whether there are stable individual differences in shifting the decision criterion. Prior research has suggested that criterion shifts can occur with various experimental manipulations and there seem to be individual differences in who is likely to shift criterion. Aminoff et al. (2012) examined criterion shifting in different versions of an item recognition task with faces and words. They found that criterion shifting was reliable across different materials with some individuals being more likely to shift criterion than others. Furthermore, they found a relation between criterion shifting and overall memory ability measured by *d*′ from the same tasks. Additionally, individual differences in criterion shifting were related to some independent measures. In particular, eight of 50 measures indicated a relation with criterion shifting. These included measures such as military rank, arrival time, alcohol habits, caffeine consumption, and two personality measures. Chen (2017) found that shifting criterion, although seemingly reliable, did not correlate with any of the cognitive ability measures. Additional research by Franks and Hicks (2016) suggested that criterion shifting on the same task across days was reliable, but correlations across different tasks were not. Franks and Hicks suggested that the reliability of criterion shifting was task dependent. Thus, much like individual differences in response bias, variation in criterion shifting seems somewhat reliable within a given task, but it is unclear whether this reflects an overall task independent trait that is linked to other cognitive abilities.

Variation in RTs in recognition studies can also be informative. Oberauer (2005) fit the diffusion model (Ratcliff, 1978) to various short-term recognition memory tasks and found a positive correlation between drift rate (i.e., the rate of accumulation of information needed for a decision) and WM. Ratcliff, Thapar, and McKoon (2010) found that intelligence was negatively (and not significantly) correlated with correct item recognition RTs. Fitting the diffusion model to the data, Ratcliff et al. found a positive correlation between drift rate and intelligence. In a follow-up study, Ratcliff, Thapar, and McKoon (2011) found that correct RTs on an item recognition task were positively (and not significantly) correlated with intelligence. Thus, unlike the prior study which found a negative correlation, this study found a positive correlation between item recognition RTs and intelligence. McKoon and Ratcliff (2012) found a negative relation between correct item recognition RTs and intelligence. Fitting diffusion models to the data in each experiment suggested relatively strong positive correlations between drift rate and intelligence, indicating that high ability participants had faster drift rates than low ability participants. Collectively, these results suggest weak relations between cognitive abilities and correct item recognition RTs.

To further examine how item recognition RTs are related to cognitive abilities data from Unsworth and Brewer (2009, 2010a) were reanalyzed. Both correct and error RTs were computed for each item recognition task. But, given that accuracy was high for the picture recognition task, error RTs were only used from the word recognition task. The correct RT factor and error RT manifest variable were allowed to correlate with each other and with the other factors. The overall fit of the model was acceptable, $\chi^2(174) = 216.01$, $p = .02$, RMSEA = .04, NNFI = .96, CFI = .97, SRMR = .06. Correct RTs and error RTs were correlated ($r = .39$). As shown in Table 4, correct RTs did not significantly correlate with any of the cognitive ability measures. This is consistent with prior work suggesting weak and nonsignificant relations. Error RTs, however, did correlate with all of the cognitive ability measures (except gC) and the correlations were positive suggesting that high ability individuals were slower to make decisions on trials where they made an error compared with low ability individuals. Given that errors tend to occur when strength is closer to threshold resulting in more difficult decisions, it is possible that high ability participants spend more time making difficult recognition decisions than low ability participants. Because the error RTs are a mix of misses and false alarms, next a model was examined in which misses and false alarm RTs were entered in as manifest variables and were allowed to correlate with one another and with the cognitive ability factors. The overall fit of the model was acceptable, $\chi^2(187) = 236.53$, $p < .01$, RMSEA = .04, NNFI = .95, CFI = .97, SRMR = .06. Miss and false alarm RTs were correlated ($r = .33$). As shown in Table 4, miss and false alarm RTs demonstrated similar positive correlations with the cognitive ability measures with the false alarm relations being somewhat stronger. Collectively, the results along with prior research suggest that correct item recognition RTs tend to be weakly related with cognitive abilities, but error RTs demonstrate stronger relations. At the same time, more research is needed to understand the potential relations and what mechanisms may be giving rise to differential relations.

Table 4
Latent Factor Correlations Between Item Recognition Reaction Time Measures and Other Cognitive Abilities

	Item recognition reaction time measures			
Factor	Correct	Error	Miss	FA
WM	**−.04**	.23	**.11**	.22
gF	**.17**	.40	.33	.31
gC	**.05**	**.15**	**.11**	**.18**
Source	**.09**	.27	**.19**	.31
FR	**−.07**	.21	.23	.19
PA	**−.10**	.30	.28	.22
Item recognition	**−.13**	.17	**.16**	.20

Note. WM = working memory; FR = free recall ; PA = paired associates; gF = general fluid intelligence; gC = general crystallized intelligence. Bold values are not significant at $p < .05$. Error, Miss, and FA reaction times are based on the item recognition memory task with words only. Item recognition refers to overall accuracy on the item recognition task. See text for details.

There are important individual differences in source recognition as well. Source recognition refers to tasks that require participants to decide not only if the item was presented during study, but also discriminate the source of the item (male or female voice, spatial location, color of items, etc.). In a large scale study Siedlecki, Salthouse, and Berish (2005) had participants ($N = 330$) perform several source recognition tasks along with other cognitive ability measures. Siedlecki et al. found that the different source recognition tasks correlated and loaded on the same factor and this factor was strongly related to executive functioning, gF, LTM, and processing speed (all *r*s > .75), but was not related to gC. Unsworth and Brewer (2009) found that a source recognition factor was related to recall, item recognition, and judgment of recency factors and to WM and gF. Unsworth and Brewer (2010a; see also Rose, 2013) found that the same source recognition factor strongly predicted individual differences in intrusion errors, but was unrelated to gC. Lilienthal et al. (2015) found that WM and source recognition were moderately correlated and the correlation between WM and source recognition was stronger than the relation between WM and item recognition similar to Unsworth and Brewer (2009). Thus, prior research suggests that there are systematic individual differences in source recognition.

Individual differences analyses of recognition have not only focused on various different types of recognition and different measures computed from these tasks, but these studies have also tried to distinguish between potential theoretical models of recognition. In particular, some studies have attempted to use individual differences analyses to test between dual-process and single process models of recognition. Dual-process models of recognition assume that performance on recognition tasks is driven by two separate processes: a fast-acting, fairly automatic familiarity process and a slower more controlled recollection process (Jacoby, 1991; Yonelinas, 2002). In many cases these two processes will lead to the same response. However, in situations requiring finer discriminations among items the familiarity processes may lead to an incorrect response, and thus there will be a greater need for the controlled recollection process to recover information related to the target item. Thus, item and source recognition should be related to the extent that both rely on recollection, and to a lesser extent familiarity. Similarly, according to dual-process models, both item recognition and source recognition should be related to recall measures to the extent that the tasks rely on recollection. In contrast, single-process models suggest that performance is not driven by separate mechanisms; rather, performance on nearly all explicit episodic memory tasks is driven by a single mechanism (memory strength).

To examine these models a number of recent studies have examined different tasks with individual differences analyses. For example, Oberauer (2005) found that recollection correlated with WM, but familiarity did not. Similarly, Quamme, Yonelinas, Widaman, Kroll, and Sauvé (2004) had 54 hypoxic patients perform a number of memory tasks and tested single-process and dual-process models via structural equation modeling. Quamme et al. (2004) found that the dual-process recognition model fit the data quite well, and that the recollection factor was significantly correlated with verbal fluency, age, and coma duration (see also Migo et al., 2014; Yonelinas et al., 2007). Using a large sample of tasks and participants, Unsworth and Brewer (2009) found that a two-factor model separating recollection and familiarity fit the data very well, and the recollection factor was related to WM, gF, and judgments of recency. The familiarity factor was only related to gF. Collectively, these results suggest that there are two sources of variance in recognition tasks; with one source (recollection) demonstrating greater correlations with other LTM and cognitive ability measures than the other source (familiarity).

Another way of examining individual differences in recollection and familiarity is to examine variation in remember and know responses (Tulving, 1985). Using this paradigm several studies have suggested that remember responses (thought be based on recollection) are related to various cognitive abilities, whereas know responses (thought to be based on familiarity) typically are not as related to cognitive abilities. For example, Salthouse and Siedlecki (2007) found that remember responses were related to LTM abilities (but were unrelated to gF, gC, and processing speed), whereas know responses did not significantly correlate with any of the cognitive ability measures. Similarly, McCabe et al. (2009) found that remember hits were positively related to LTM (but unrelated to executive functioning), and know hits were uncorrelated with both LTM and executive functioning. Remember false alarms were negatively related to both executive functioning and LTM, whereas know false alarms were only negatively related to executive functioning. These results suggest that recollection (remember responses) tend to be more related with other LTM memory abilities than familiarity (know responses).

Across a number of studies recollection seems be more related to other cognitive abilities than familiarity. This naturally begs the question as to whether familiarity is consistently related to any other cognitive ability. According to some dual-process theories, familiarity and implicit memory likely rely on the same underlying processes and thus, should be related (Jacoby, 1991; Yonelinas, 2002). To examine this, Wang and Yonelinas (2012) had 53 participants first incidentally encode a large number of words followed by a surprise recognition test on some of the words. Finally, participants performed a free association task in which some of the words were associated with the encoded words to estimate implicit priming. Wang and Yonelinas found that familiarity was related to priming ($r = .47$), but recollection was not ($r = -.15$). In an additional experiment Wang and Yonelinas had 21 participants perform the same tasks, but with the addition of remember and know responses in the recognition task. They found that know responses were related to priming, but remember responses were not. These results suggest that familiarity is related to individual differences in priming, whereas recollection is not. At the same time, the results are based on very small sample sizes and single tasks and need to be replicated with more powerful designs to ensure their stability.

Like other LTM tasks there are large and important individual differences in recognition memory. Variability across different recognition tasks using different metrics of performance tend to correlate and load on the same factor which is related to other LTM factors and to other cognitive abilities. Echoing Hollingworth's (1913) claim there are clear individual differences in recognition memory, but more work remains to be done to further elucidate the nature of this variation.

Individual Differences in Other Aspects of Long-Term Memory

In the next sections individual differences in various aspects of LTM including forgetting, interference control, false memories, testing, and so forth are examined in more detail.

Individual Differences in Forgetting

The time course of forgetting has long interested memory researchers (Ebbinghaus, 1885/1964). One contentious issue with regard to forgetting functions is the extent to which initial levels of learning and subsequent rates of forgetting are associated. Some authors have suggested that level of initial learning and rate of forgetting are independent (e.g., Bogartz, 1990; Slamecka, 1985), whereas others have suggested that they are not independent (e.g., Loftus, 1985). For example, early work by Gillette (1936) suggested that faster initial learners tended to forget less (retain more) than slow initial learners. McGeoch and Irion (1952) noted that "By and large, individual differences in learning are reflected in individual differences in retention" (p. 325). However, Underwood (1954, 1964) suggested that there are no differences in the rate of forgetting for fast and slow learners once the degree of initial learning is taken into account. Specifically, if participants are equated on initial learning (via various techniques), then forgetting rates tend to be similar for fast and slow learners (see also Gentile, Monaco, Iheozor-Egiofor, Ndu, & Ogbonaya, 1982; Schoer, 1962; Shuell & Keppel, 1970). For example, Stroud and Schoer (1959) found positive correlations between initial rate of learning and retention and suggested that these correlations were slight and provided weak evidence for the notion that individual differences in forgetting occur once initial learning is taken into account. Similarly, Shuell and Keppel (1970) suggested that there are few differences between fast and slow learners after 24 and 48 hr retention intervals when the degree of initial learning is equated across participants. Both Ferretti (1982) and Larson (1993) found that high and low ability participants exhibited largely parallel forgetting functions. Thus, some prior research suggests that there are no (or very slight) individual differences in forgetting once initial learning is taken into account.

At the same time other research suggests there are individual differences in forgetting independent of initial learning. For example, Fraser (1974) had high and average intelligence students perform a delayed free-recall task. High intelligence students were presented with words at 1 s per word, whereas the average intelligence students were presented with the words at 5 s per word to equate initial levels of recall across the groups. Intelligence was positively correlated with recall after 35 days. Thus, unlike Shuell and Keppel (1970) which showed similar forgetting rates for fast and slow learners, Fraser (1974) suggested that high and average intelligence individuals did differ in their rate of forgetting. Kyllonen and Tirre (1988) found that fast learners tended to forget less than slow learners regardless of initial degree of learning. Likewise, Wixted and Ebbesen (1997) fit power functions to individual participant's data and found large variation in both the intercept and slope, suggesting that individuals do not simply differ in overall levels of performance, but that differences can arise due to differences in initial levels of recall and/or differences in forgetting rates. In another study examining the time course of forgetting, Rubin, Hinton, and Wenzel (1999) had participants perform a running paired associates task in which after a variable number of intervening cue-target pairs (0, 1, 2, 4, 7, 12, 21, 35, 59, or 99), participants were presented with the cue word and were required to recall the target word that was paired with the cue word. Rubin et al. fit a three-parameter function to the forgetting curves (one parameter for WM, one parameter for the middle portion of the curve, and one parameter for asymptote). They found that the two LTM parameters correlated with ACT scores, such that high and low ACT scorers had similar recall levels at very short lags, but that low ACT scorers had a larger drop in performance (and a lower asymptote) than high ACT scorers. Using the same running paired associates task as Rubin et al. (1999), Unsworth, Brewer, and Spillers (2011b) found that high and low WM individuals had similar recall levels when tested immediately (i.e., lag of zero), but that low WM individuals demonstrated greater forgetting at longer lags than high WM individuals. Similarly, Zimprich and Kurtz (2013), utilizing a latent change model found that WM and processing speed predicted overall forgetting over a 30-min interval. Collectively, these results suggest that there are reliable individual differences in forgetting with high ability individuals demonstrating less forgetting than low ability individuals.[4]

In perhaps the most thorough examination of individual differences in forgetting, MacDonald, Stigsdotter-Neely, Derwinger, and Bäckman (2006) had 136 participants learn 4-digit numbers to perfection. To control for possible variation in encoding strategies, MacDonald et al. had participants all train on the same mnemonic technique prior to the study. Once all participants had learned the numbers to criterion they were retested 30 min, 24 hr, 7 weeks, and 8 months later. MacDonald et al. found that there were reliable individual differences in forgetting even when participants were equated on initial learning, contrary to Underwood (1954). In fact, average fast learners forgot 58% of the items over the 8 month delay, whereas average slow learners forgot 77% of the items. Furthermore, MacDonald et al. found that LTM, WM, and processing speed (but not verbal fluency) predicted individual differences in forgetting rates. Entering all of the predictors simultaneously into a model suggested that learning speed was the weakest predictor whereas LTM was the strongest predictor. Thus, individuals high in LTM abilities tended to forget less than individuals low in LTM abilities even after controlling for individual differences in learning speed, speed of processing, and WM. These results strongly suggest that there are robust individual differences in LTM forgetting and that individual differences in LTM abilities are one of the primary predictors of variation in forgetting.

Additional evidence for this claim comes from a study by Unsworth (2007a; unpublished) in which participants (N = 131) performed the same running paired associates task (with lags 0, 1, 2, 4, 7, 12, 21, 35, 59, or 99 intervening cue-target pairs) as Rubin et al. (1999) and Unsworth et al. (2011b), along with multiple measures of LTM, WM, gF, and gC. Reanalyzing the data in which composites of LTM, WM, gF, and gC were entered as covariates in an ANCOVA suggested that only LTM significantly interacted with lag, $F(9, 1134) = 2.98$, $MSE = .02$, $p = .002$, partial $\eta^2 = .02$ (all other $ps > .15$). This is illustrated in Figure 12, which shows forgetting curves for high and low LTM participants. Low LTM individuals demonstrated a greater drop in performance and an overall lower asymptote than high LTM individuals suggesting that, similar to MacDonald et al. (2006), high LTM individuals forget less than low LTM individuals.

Another way of examining these data is to utilize latent growth curve models within a structural equation modeling framework (see Hertzog & Nesselroade, 2003) to examine whether variation in forgetting occurs due to initial performance, to changes in performance, or some combination of both. A latent growth curve model was specified in which all lags loaded equally onto the intercept factor and the slope factor was modeled as a single nonlinear variable by fixing the loading of lag zero to 0 and the lag 99 loading was set to 1.0 with the other lags free to vary. Note that a model in which the slope factor was modeled with each lag loading equal to the lag value (i.e., 0–99) resulted in overall similar results. The growth model showed an acceptable fit to the data, $\chi^2(36) = 51.15$, $p = .05$, RMSEA = .06, NNFI = .98, CFI = .99, SRMR = .12. The intercept and slope were correlated ($r = -.57$) indicating that participants who started out with a high initial level of performance tended to forget less in accord with prior research. Next LTM, WM, gF, and gC were added to the model to see if these cognitive abilities correlated with the slope and intercept factors. The model fit was good, $\chi^2(217) = 270.70$, $p = .008$, RMSEA = .04, NNFI = .96, CFI = .97, SRMR = .09. As shown in Table 5, all of the cognitive ability factors correlated with the intercept. However, only individual differences in LTM abilities were related to the slope factor suggesting that individuals high in LTM abilities tended to forget less than individuals low in LTM abilities consistent with the ANCOVA results and prior research.

Although some prior research suggested that there are no individual differences in forgetting once initial levels of performance are taken into account, more recent research suggests that there are reliable individual differences in forgetting. This variation tends to be related to other cognitive abilities and in particular is related to individual differences in overall LTM abilities. Understanding the mechanisms that give rise to individual differences in forgetting is a critical next step.

Individual Differences in Interference Control

Theoretically, one key reason why we forget is because similar memories interfere and compete for access to WM. In experimental paradigms interference is typically associated with a drop in performance when interfering items are present compared with when they are not. This can occur because items presented before the target items are interfering (proactive interference) or because items presented after the target items are interfering (retroactive interference). Given the importance of interference for forgetting (see Anderson & Neely, 1996 for a review), one natural question is whether there are individual differences in susceptibility to interference or interference control. Jensen (1964) conducted an important early study of individual differences in both proactive and retroactive interference using memory span and serial learning

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[4] There are also individual differences in list-method directed forgetting in which high ability participants typically show more directed forgetting than low ability participants (e.g., Aslan, Zellner, & Bäuml, 2010; Delaney & Sahakyan, 2007; Soriano & Bajo, 2007) and directed forgetting is associated with some personality measures (Delaney, Goldman, King, & Nelson-Gray, 2015).

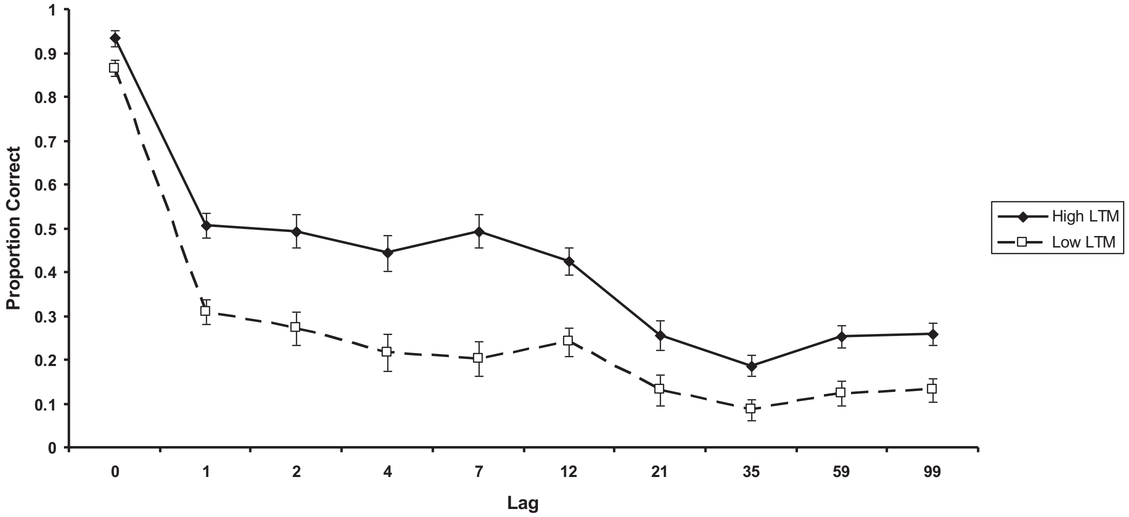

Figure 12. Proportion correct as a function of lag for high and low long-term memory (LTM) participants. Error bars reflect one standard error of the mean. Data from Unsworth (2007a).

tasks. Jensen did a number of detailed analyses on each task, but for the present purposes the most telling analyses involved correlations between the different interference tasks and factor analysis of the different tasks in a sample of 50 participants who completed all of the measures. Jensen found that for the memory span tasks retroactive and proactive interference were positively correlated ($r = .28$). Examining the correlations with factor analysis Jensen found evidence for 12 factors, three of which were considered interference factors (one for retroactive interference in the memory span tasks and supraspan lists, one for interference in serial learning, and another for intralist interference in serial learning). All of these factors were moderately correlated with one another. Despite a limited number of participants who completed all tasks and restriction of range (all participants were Berkeley students) this study provides early important evidence for the notion that there are reliable individual differences in interference susceptibility.

Following up on Jensen's (1964) research, Berger and Goldberger (1979) also found evidence for an interference factor. Carroll (1993) reanalyzed Berger and Goldberger's data and suggested the presence of three factors (one for retroactive interference, one for proactive interference, and one for immediate memory span). Importantly the retroactive and proactive interference factors were correlated ($r = .28$) suggesting that similar to Jensen (1964) that retroactive and proactive interference are separate, yet related.

In their seminal study, Underwood et al. (1978) also included a measure of interference control. This task consisted of paired associates tasks in which on each successive list response and stimulus terms were recombined to increase interference across lists. Underwood et al. noted that the interference control measure did not strongly correlate with any of the other tasks although it tended to correlate moderately with nearly all the measures around .20–.30. Given that it did not strongly correlate with any one set of tasks, Underwood et al. did not include it in their final factor analysis, but noted that it did seem to index individual differences in susceptibility to interference as intended. To get a better sense of how the interference control measure related to the other factors a confirmatory factor analysis was specified in which the interference control measure was added to the model depicted in Figure 2 as a manifest variable. The overall fit of the model was good, $\chi^2(138) = 242.21$, $p < .001$, RMSEA = .06, NNFI = .97, CFI = .98, SRMR = .06. As shown in Table 6, interference control was correlated with all of the LTM factors with stronger relations occurring for the serial learning and discrimination tasks. Next, to get an idea of how interference control is related to overall LTM abilities and to other cognitive abilities, the same higher-order factor model depicted in Figure 2b was specified along with factors for WM, gC, and SAT scores (see Table 1), and interference control was included as a manifest variable. The overall fit of the model was good, $\chi^2(285) = 512.63$, $p < .001$, RMSEA = .06, NNFI = .96, CFI = .96, SRMR = .08. As shown in Table 6, interference control correlated strongly with the higher-order LTM factor and correlated with WM (based on the memory span tasks). However, it did not significantly correlate with either gC or SAT scores. Although based on only a single measure of interference control, these results suggest that individual differences in inter-

Table 5
Latent Factor Correlations for Intercept and Slope Based on a Latent Change Model of Forgetting With Latent Factors for Long-Term Memory, Working Memory, Fluid Intelligence, and Crystallized Intelligence

Factor	Intercept	Slope
LTM	.57	−.35
WM	.26	**−.10**
gF	.46	**−.03**
gC	.32	**−.09**

Note. Bold values are not significant at $p < .05$. LTM = long-term memory; WM = working memory; gF = general fluid intelligence; gC = general crystallized intelligence.

Table 6
Latent Factor Correlations Between the Interference Control Measure With Latent Factors for Free Recall, Paired Associates, Serial Learning, Discrimination, Recognition, Higher-Order Long-Term Memory, Working Memory, Crystallized Intelligence, and SAT Scores

Factor	Interference control
FR	.33
PA	.30
SL	.46
Dis	.50
Rec	.29
LTM	.44
WM	.31
gC	**.12**
SAT	**.02**

Note. Bold values are not significant at $p < .05$. FR = free recall; PA = paired associates; SL = serial learning; Dis = discrimination; Rec = recognition memory; LTM = higher order long-term memory; WM = working memory; gC = general crystallized intelligence; SAT = Scholastic Aptitude Test scores. Data from Underwood et al. (1978). See text for discussion.

ference susceptibility are related to overall LTM abilities and to WM.

Taking a more experimental approach Hunt et al. (1973) had participants perform a version of the Brown-Peterson task (Brown, 1958; Peterson & Peterson, 1959) in which participants were given words from the same category (vegetables) on three successive trials to allow for a build-up of proactive interference. On the fourth trial participants were either presented with words from a new category (occupations) to assess release from proactive interference or words from the same category as the prior lists (e.g., Wickens, 1972; Wickens, Born, & Allen, 1963). Hunt et al. found that low verbal participants tended to recall fewer items overall, but showed similar proactive interference build-up functions as high verbal participants. Interestingly, the low verbal participants demonstrated much weaker release functions than the high verbal participants especially when serial recall scoring was used. This is consistent with other research suggesting that some groups (e.g., Korsakoff patients and institutionalized older adults) do not show a release from proactive interference when a category is switched (e.g., Winocur, Kinsbourne, & Moscovitch, 1981; Moscovitch & Winocur, 1983). Thus, although there weren't really any differences in susceptibility to proactive interference, there was some evidence for differences in release from proactive interference.

Dempster and colleagues (Dempster, 1985; Dempster & Cooney, 1982; Dempster & Corkill, 1999) have long suggested that individual differences in interference control are a critical source of individual differences in cognitive abilities. For example, Dempster and Cooney (1982) had participants ($N = 28$) perform a version of the Brown-Peterson task with category switches and found that a measure of interference susceptibility was weakly (and not significantly) related to WM, but was related to scores on the SAT and Nelson-Denny. Although these results are consistent with prior and more current research, it should be noted that the lack of some of the relations in this study is likely attributable to the fact that (a) the study is underpowered with only 28 total participants and only 22 participant having available aptitude scores, and (b) the main measure of interference is a differences score between accuracy on low interference trials and high interference trials. Although not always the case, difference scores tend to have low reliabilities, which places a limit on the magnitude of observed correlations that can be found. In more recent research Dempster and Corkill (1999) reported a study in which participants ($N = 92$) performed a paired associates task in which intrusion errors were taken as the measure of interference and found that intrusions were correlated with the other paired associates measures (overall correct), block design, and math aptitude. These results suggest that susceptibility to interference on LTM tasks demonstrates some relations with other measures of cognitive abilities. Furthermore, susceptibility to interference in higher-order tasks like reading comprehension is also related to cognitive abilities. For instance, several studies have shown that proactive interference accrues in reading comprehension tasks (e.g., Blumenthal & Robbins, 1977; Dempster, 1985) and susceptibility to proactive interference was related to ACT scores (Dempster, 1985; although these results should be viewed with caution given that there were only 16 participants in the study). Thus, not only is proactive interference susceptibility an important factor in memory tasks, it is also important in higher order cognitive tasks, suggesting that the common variance shared between these tasks represents an ability to retrieve information in the presence of competition.

Consistent with the results from Underwood et al. (1978) suggesting that WM is related to interference control, a number of studies have found relations between WM measures and interference measures in a number of paradigms. For example, Cantor and Engle (1993) found differential fan effects (Anderson, 1974) for high and low WM participants (see also Bunting, Conway, & Heitz, 2004). Cantor and Engle also found that the correlation between WM and Verbal SAT scores was reduced when the slope of the fan effect for each individual participant was partialed out. Conway and Engle (1994) found that high and low WM individuals only differed on a probe-recognition task when interference was present. Rosen and Engle (1998) demonstrated that low WM individuals were more susceptible to interference in a paired associates task than high WM individuals. Similarly, Kane and Engle (2000) found that low WM individuals demonstrated a greater build-up of proactive interference than high WM individuals (although they demonstrated equivalent release effects). Consistent with prior research, these results suggest that individual differences in interference control are consistently related to individual differences in WM (see also Borella, Carretti, & Mammarella, 2008; Bunting, 2006; Kliegl, Pastötter, & Bäuml, 2015; Lustig, May, & Hasher, 2001).

Returning to latent variable models of interference susceptibility, Chaiken (2001) reported two experiments examining whether interference control from paired recognition tasks was separate from overall baseline memory abilities. Participants ($N = 811$ Air Force trainees) completed six paired recognition tasks along with a procedural learning task. Chaiken constructed a bifactor model in which all of the pair recognition tasks loaded onto the baseline memory factor (assuming that all tasks require some basic memory abilities) and a resistance to interference factor in which only the interference tasks loaded on it (assuming that there is something unique about these tasks over and above abilities in the baseline task). Chaiken found that this model fit the data fairly well and each factor accounted for some unique variance in procedural learning. Furthermore, Chaiken found that the interference factor was not related to the ASVAB factor suggesting that susceptibility to interference was not related to gC consistent with prior research. One thing to note from these results it that they suggest that baseline memory abilities and interference susceptibility are unrelated. However, this is a direct consequence of how the data were modeled. Specifically, with a bifactor model of this sort interference susceptibility is the residualized variance after taking into account baseline abilities from the same tasks. Thus, they there are necessarily uncorrelated. This does not mean that LTM abilities broadly defined and interference susceptibility are unrelated, rather as seen above (and below), these two tend to be moderately to strongly correlated.

In a highly cited paper, Friedman and Miyake (2004) examined individual differences in inhibition and interference control functions. In this study 220 undergraduate students performed a number of tasks thought to assess resistance to proactive interference, prepotent response inhibition, and resistance to distractor interference. Initially, resistance to proactive interference scores were based on subtracting lists where interference was high from lists were interference was low. Unfortunately, reliability for these measures were very low (.08–.12). Specifying a three-factor model with separate factors for resistance to proactive interference, prepotent response inhibition, and resistance to distractor interference suggested a good fit to the data. In this model both prepotent response inhibition and resistance to distractor interference were correlated, but neither was correlated to resistance to proactive interference. Friedman and Miyake reasoned that this lack of relations was likely due to the poor reliabilities associated with the difference score measures. They specified a new model of resistance to proactive interference in which List 1 recall on each task formed a latent factor and List 2 from each task formed another latent factor. The List 1 factor then predicted the List 2 factor and the residualized variance (i.e., variance left over after accounting for List 1) was taken as the measure of resistance to interference similar to Chaiken (2001). Friedman and Miyake found that the List 1 factor correlated with a combined response-distractor inhibition factor ($r = -.43$), suggesting that basic memory abilities are related to inhibitory control/attention control abilities similar to what was examined previously. The resistance to proactive interference factor, however, was not related to the inhibitory control factor ($r = .01$). Thus, a major conclusion from this study was that interference susceptibility in memory tasks was unrelated to interference susceptibility from attention control tasks. In subsequent analyses Friedman and Miyake found that the only measures that were predicted by the resistance to proactive interference factor were a measure of WM (reading span) and unwanted intrusive thoughts. Thus, this study provides important information suggesting that interference susceptibility to inferring memorial representations is an important individual differences construct that is related to some abilities, but is not necessarily related other conceptually similar abilities. However, it should be noted that Stahl et al. (2014) found a relation between an interference factor (composed of the recent probes task and two directed forgetting tasks) and factor composed of inhibition/attention control tasks. Thus, additional research is needed to replicate potential relations.

In another large-scale latent variable study, Salthouse, Siedlecki, and Krueger (2006) examined memory control or interference control in a sample of 328 adults. Participants performed multiple measures of gF, LTM, processing speed, and gC, along with seven interference control tasks. Salthouse et al. found that the interference control measures (difference scores) all tended to have poor reliabilities and the measures demonstrated weak correlations with each other. Salthouse et al. planned to form a latent interference control factor and see how this factor was related to other cognitive abilities, but given that the measures did not demonstrate convergent validity at the zero-order correlation level, a latent factor could not be formed. Examining each task separately suggested that the variables only seemed to be related to LTM. Given the lack of evidence for an interference susceptibility (or interference control) factor in their study, Salthouse et al. suggested that it was still an open question as to interference measures are related to one another and to other cognitive abilities.

Unsworth (2010b) also examined individual differences in interference control at the latent level. In this Study 161 undergraduates completed multiple measures of WM, gF, and gC and three interference control tasks. In each task measures of interference (three differences scores and total number of lure intrusions in the cued recall task) were obtained along with baseline memory measures (performance on low interference lists). The interference measures had generally weak reliability estimates although they were better than what was found in prior studies (i.e., reliability ranging from .40–.64). Unsworth found that all of the interference measures were weakly correlated and loaded onto the same interference susceptibility factor. Importantly, this factor was related to overall baseline memory abilities ($r = -.69$), WM ($r = -.59$), gF ($r = -.49$), and gC ($r = -.28$). Thus, consistent with several prior studies individual differences in interference control were related to individual differences in baseline LTM abilities and WM abilities. Variation in interference control was also related to aspects of intelligence suggesting that this is an important source of individual differences in cognitive abilities.

To further examine relations between interference control and other cognitive abilities, data from three prior latent variable studies were reanalyzed. In the first reanalysis data from Unsworth and Brewer (2009, 2010a) were examined. In this study participants performed a version of the Brown-Peterson task with proactive interference build and release based on Kane and Engle (2000). To examine individual differences in interference control a bifactor model was specified similar to that used by Chaiken (2001; see also Friedman & Miyake, 2004) in which two factors were formed based on the Brown-Peterson task. In the first factor all three trials were allowed to load onto it representing baseline recall abilities in the task. In the second factor only trials two and three were allowed to load onto it representing additional abilities needed on these trials due to the buildup of proactive interference. The correlation between the two factors was set to zero. Thus, the first factor represents overall baseline recall abilities, whereas the second factor represents additional abilities needed on proactive interference build trials after taking into account baseline abilities. These two factors were then allowed to correlate with the other cognitive ability factors. The overall fit of the model was good, $\chi^2(185) = 203.34$, $p = .169$, RMSEA = .02, NNFI = .98, CFI = .98, SRMR = .05. Shown in Table 7 are the correlations between the baseline recall ability and proactive interference control factors with the other cognitive ability factors. Note that the correlations between the interference control factor and other abilities are

Table 7
Correlations Between Baseline Recall Ability and Proactive Interference Control Factors From the Brown-Peterson Task With Latent Factors for Free Recall, Paired Associates, Source Recognition, Item Recognition, Judgements of Recency, Working Memory, Fluid Intelligence, and Crystallized Intelligence

Factor	Baseline recall	Interference control
FR	.41	.31
PA	.43	**.16**
Source	.34	**.14**
Rec	.36	**−.02**
JOR	**.03**	**.16**
WM	.22	.23
gF	.22	.28
gC	**−.02**	.26

Note. Bold values are not significant at $p < .05$. FR = free recall; PA = paired associates; Source = source recognition; Rec = item recognition memory; JOR = judgements of recency; WM = working memory; gF = general fluid intelligence; gC = general crystallized intelligence. Data from Unsworth and Brewer (2009, 2010a). See text for discussion.

positive indicating greater recall abilities (i.e., better interference control) is positively related to other cognitive abilities. As can be seen, all of the cognitive ability factors (except for judgments of recency and gC) correlated with baseline recall abilities. Examining interference control suggested that of the different LTM factors only the free recall factor correlated significantly with the interference control factor. However, WM, gF, and gC all correlated with the interference control factor. Thus, these analyses suggest that there are (at least) two sources of variance associated with recall on Brown-Peterson trials where interference is present: baseline recall abilities, and interference control. These two measures differentially correlate with other LTM factors and with other cognitive abilities.

A similar reanalysis was done for data from Unsworth and Spillers (2010a). In this study participants performed the same Brown-Peterson task as Unsworth and Brewer (2009, 2010a) along with additional measures of LTM, WM, gF, and AC. Thus, this reanalysis should allow for a replication of the prior results as well as to examine whether interference control relates to AC. Recall that a unique finding from Friedman and Miyake (2004) was that interference control was not correlated with response-distractor inhibition factor even though baseline recall abilities were correlated with the inhibition factor. The response-distractor inhibition factor in that study is very similar to the AC factor discussed throughout given that both factors are composed of tasks such antisaccade, Stroop, and Flankers. The same bifactor was model was specified as above with separate baseline recall and interference control factors. These two factors were allowed to correlate with the LTM, WM, gF, and AC factors. The overall fit of the model was good, $\chi^2(88) = 96.94$, $p = .241$, RMSEA = .02, NNFI = .98, CFI = .99, SRMR = .05. Shown in Table 8 are the correlations between the baseline recall ability and proactive interference control factors with the other cognitive ability factors. Similar to prior research LTM and WM were correlated with both baseline recall abilities and interference control. gF was related to baseline recall abilities, but here it was not related to interference control. Importantly, replicating Friedman and Miyake (2004) AC (or what they called response-distractor inhibition) was related to baseline recall abilities, but was not related to interference control (but see Stahl et al., 2014). Thus, the ability to control interference in memory is not necessarily the same ability as controlling interfering perceptual information.

In the final reanalysis examining interference control abilities, data from Unsworth (2010a) were examined. Rather than examining interference control from a single measure, here interference control across several measures is examined. Specifically, in this study participants performed the same Brown-Peterson task as before along with a cued recall directed forgetting task from Tolan and Tehan (1999; see also Friedman & Miyake, 2004; Unsworth, 2010a). In both tasks, an overall proactive interference measure (low interference trials minus high interference trials) was computed as well as overall number of intrusion errors as separate measures of interference. Participants also performed a variant of the list-before-last task developed by Shiffrin (1970b; Ward & Tan, 2004) in which participants were presented with two lists of 10 words each and were told to remember both lists. At recall, participants were cued to recall either List 1 or List 2. Thus, participants had to recall List 1 in the presence of List 2 (retroactive interference) or recall List 2 in the presence of List 1 (proactive interference). Overall proportion correct on each list as well as the number of List 1 and List 2 intrusions were the measures from this task. Thus, rather than having only a single measure of interference (typically a single difference score), here there are seven different measures including interference difference scores, proportion correct, and intrusion errors. This should make for a more stable interference control factor. All of these measures were allowed to load onto the interference control factor and this factor was allowed to correlate with LTM, WM, gF, and gC factors. The overall fit of the model was acceptable, $\chi^2(220) = 488.30$, $p < .001$, RMSEA = .09, NNFI = .88, CFI = .90, SRMR = .08. Shown in Figure 13 is the resulting model. As can be seen, all of the interference measures loaded significantly on the interference control factor. Although the two proactive interference differences scores tended to load weakly. This factor was significantly related to all of the other cognitive ability factors with the strongest relation occurring with the LTM factor.

Prior research suggests that there are distinct and important individual differences in the ability to control interference (or susceptibility to interference) from competing memory represen-

Table 8
Correlations Between Baseline Recall Ability and Proactive Interference Control Factors From the Brown-Peterson Task With Latent Factors for Long-Term Memory, Working Memory, Fluid Intelligence, and Attention Control

Factor	Baseline recall	Interference control
LTM	.64	.37
WM	.19	.27
gF	.27	**−.09**
AC	.41	**.14**

Note. Bold values are not significant at $p < .05$. LTM = long-term memory; WM = working memory; gF = general fluid intelligence; AC = attention control. Data from Unsworth and Spillers (2010a). See text for discussion.

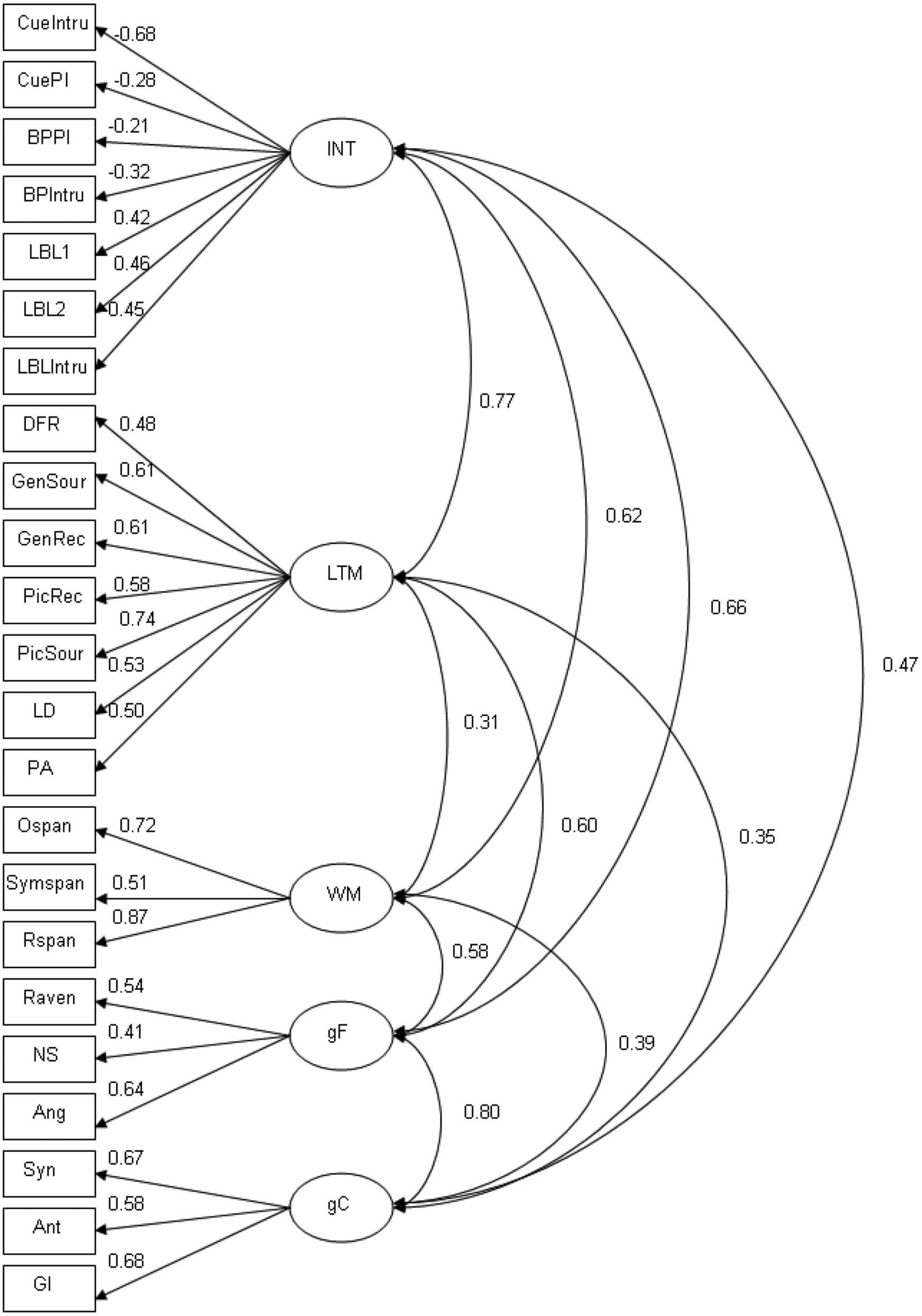

Figure 13 (*opposite*).

tations. A common theme across studies is that interference control measures tend to correlate and form a factor, but this strongly depends on the measures used to estimate interference control abilities. When only difference scores with poor reliabilities are used, there is weak evidence for a common interference control factor. When difference scores with more acceptable reliabilities are used, or when differences scores are combined with other measures (such as proportion correct on interference trials, residualized interference measures after accounting for baseline recall abilities, and intrusions errors) a more coherent and stable interference control factor tends to emerge. Across studies interference control abilities are consistently related to LTM abilities (particularly free recall abilities) and WM. These relations occur even when taking into account differences in baseline recall abilities. Theoretically variation in interference control abilities could arise due to variation in inhibition or suppression (Hasher, Lustig, & Zacks, 2007; Kane, Conway, Hambrick, & Engle, 2007), or variation in contextual retrieval processes whereby low ability individuals are less able to generate and specify cues that focus the search on the current trial (Unsworth & Engle, 2007). Future research is needed to better examine the nature of individual differences in interference control (i.e., are individual differences in susceptibility to proactive interference and retroactive interference the same, related, or distinct?), examine relations between interference control and other cognitive abilities (in particular the lack of a relation with AC/response-distractor inhibition), and test competing hypotheses regarding the potential underlying mechanism(s) for variation in interference control abilities.

Individual Differences in False Memory

A number of recent studies have suggested that there are individual differences in susceptibility to false memories. One of the most common paradigms for studying false memories is the Deese-Roediger-McDermott (DRM; Deese, 1959; Roediger & McDermott, 1995) paradigm (see Gallo, 2010, for a review). In the DRM paradigm, participants are presented with a list of words which are all related to a common word (e.g., sleep) and are asked to recall all of the words that were presented. Critically, the nonpresented word (sleep) tends to be falsely recalled with a high probability (see Gallo, 2010 for a review). Psychometrically both recall and recognition versions tend to be demonstrate adequate reliability including test-retest (Blair, Lenton, & Hastie, 2002) and internal consistency (Calvillo & Parong, 2016; Salthouse & Siedlecki, 2007; Unsworth & Brewer, 2010a; but see Lövdén, 2003). Furthermore, Ost et al. (2013) found that recall of lures was correlated with recognition of lures ($r = .56$). Thus, at an individual differences level responses to lures in both recognition and recall in the DRM tend to have adequate reliability.

In one of the first studies to examine individual differences in susceptibility to false memories, Winograd, Peluso, and Glover (1998) examined the correlation between false recall and false recognition in the DRM paradigm with a variety of cognitive and personality measures. Winograd et al. found that self-reports on the Dissociative Experiences Scale, the Vividness of Visual Imagery Questionnaire, and the Subjective Memory Questionnaire were all correlated with measures of false recognition in the DRM paradigm. Winograd et al. suggested that the relations found among the self-report measures and susceptibly to false memories arose due to failures in source monitoring. Those individuals who were likely to report a greater frequency of dissociative experiences had greater vivid mental imagery abilities and reported more everyday memory failures. However, it should be noted that the relation between DRM and the Dissociative Experiences Scale has not always replicated. For example, Platt, Lacey, Iobst, and Finkelman (1998) and Wilkinson and Hyman (1998) failed to find reliable relations between DRM lures and the Dissociative Experiences Scale. Important for the current discussion, Winograd et al. (1998) found that several of the cognitive measures including verbal fluency, vocabulary, and verbal SAT scores were unrelated to lures in the DRM. Thus, although intrusions in free recall have been found to be related to a number of cognitive abilities, in Winograd et al. no such relations were found.

In another study, Lövdén (2003) had 146 adults (ages 20–80) perform a number of tasks thought to elicit false memories including category cued recall, DRM, and a picture recognition task. Using confirmatory factor analysis, Lövdén found that the three false memory tasks all loaded onto the same factor and this factor was related to both an inhibition factor ($r = -.38$ corrected for age; see also Colombel, Tessoulin, Gilet, & Corson, 2016) and a LTM factor ($r = -.59$ corrected for age). In a structural equation model, Lövdén found that inhibition predicted LTM and LTM predicted false memories, but inhibition did not uniquely predict false memories. Thus, individual differences in LTM were found to account for a large portion of individual differences in false memories. Inhibitory abilities (or AC) were less predictive of individual differences in false memories, especially after taking into account individual differences in LTM. Thus, it is unlikely that individual differences in the ability to suppress lure representations accounts for individual differences in false memories in the DRM. Rather variation in false memories seems strongly tied to overall LTM abilities.

Whereas Lövdén (2003) found evidence for relations between false memories in the DRM and other cognitive abilities, Salthouse

Figure 13 (*opposite*). Confirmatory factor analysis with interference control (INT), long-term memory (LTM), working memory (WM), fluid intelligence, (gF), and crystallized intelligence factors. Solid paths are significant at the $p < .05$ level. CueIntru = lure intrusions from cued recall directed forgetting task; CuePI = proactive interference on cued recall directed forgetting task; BPPI = proactive interference Brown-Peterson; BPIntru = intrusions on Brown-Peterson; LBL1 = list-before-last List 1 recall; LBL2 = list-before-last List 2 recall; LBLIntru = intrusions on list-before-last recall; DFR = delayed free recall; Gensour = gender source recognition; Genrec = gender recognition; Picrec = picture recognition; Picsour = picture source recognition; LD = list discrimination; PA = paired associates with words; Ospan = operation span; Symspan = symmetry span; Rspan = reading span; Raven = Raven Progressive Matrices; NS = number series; Ang = verbal analogies; Syn = synonym vocabulary; Ant = antonym vocabulary; GI = general information. Data from Unsworth (2010a).

and Siedlecki (2007) found the opposite. Specifically, in their first experiment with 327 participants Salthouse and Siedlecki found that false alarms to critical lures on the DRM were largely unrelated to cognitive abilities in terms of near zero correlations with LTM, gF, gC, processing speed, and a variety of personality questionnaires. In their second experiment with 332 participants, Salthouse and Siedlecki had participants perform three different recognition memory tasks with words, dots, or faces as stimuli. Examining false alarms to critical lures in each task suggested that across tasks the correlations were somewhat weak implying that false memories across different types of stimuli were not strongly related. This result in in contrast to Lövdén (2003) who found that different false memory measures tended to correlate and load on the same factor. Salthouse and Siedlecki (2007) again found generally nonexistent relations with cognitive abilities. These results suggest that individual differences in the susceptibility to false memories (in particular false recognition memories) are generally unrelated to LTM and other cognitive abilities.

Despite these inconsistent results, one source of individual differences which has demonstrated consistent relations with DRM false memories is WM. Watson, Bunting, Poole, and Conway (2005) had high and low WM perform a standard DRM free-recall task with either a prior warning or no prior warning. Watson et al. found that high and low WM individuals produced the same number of critical word intrusions in the no warning condition, but that high WM individuals recalled fewer critical word intrusions in the warning condition. Subsequent research has additionally found relations between WM and false memories in the DRM and related paradigms (e.g., Chan & McDermott, 2007; Gerrie & Garry, 2007; Peters et al., 2007). For example, Leding (2012) found that high WM individuals were less likely to have false recognition memories in the DRM than low WM individuals and that high WM individuals were more likely to use a recall-to-reject strategy than low WM individuals. The recall-to-reject strategy is a source monitoring strategy whereby individuals can reject the lure because they can specifically recall aspects of the target item. Thus, these results suggest that part of the reason for the relation between WM and false memories in the DRM are attributable to source monitoring abilities.

Collectively these studies suggest a somewhat inconsistent picture of individual differences in false memories in the DRM. Some studies find that LTM and other cognitive abilities are related to DRM false memories (Lövdén, 2003), whereas others find no relation (Salthouse & Siedlecki, 2007). Furthermore, some studies suggest that source monitoring abilities are critical to the relation between WM and false memories (Gerrie & Garry, 2007; Leding, 2012), whereas others suggest that source monitoring abilities do not play a role (Watson et al., 2005). To clarify these discrepant findings Unsworth and Brewer (2010a) conducted a study in which 177 participants completed a free recall variant of the DRM along with additional measures. As noted previously, Unsworth and Brewer found that all of the intrusion errors (PLIs and ELIs) loaded onto the same factor. Crucially, DRM critical lures also loaded onto this factor. This factor was found to correlate with several latent factors including overall recall ($r = -.49$), source monitoring ($r = -.59$), WM ($r = -.26$), judgments of recency ($r = -.25$), and gC ($r = -.25$). Thus consistent with Lövdén (2003), but inconsistent with Salthouse and Siedlecki (2007), false memories were found to correlate with a number of different cognitive abilities. Furthermore, consistent with a number of prior studies WM was related to false memories. However, subsequent mediation models suggested that the relation between WM and false memories was mediated by source monitoring. That is, once source monitoring was taken into account the correlation between WM and false memories was essentially zero. Similar results occurred when examining the other cognitive abilities suggesting that individual differences in source monitoring abilities are likely a main source of individual differences in false memories in the DRM. More recently, Ball and Brewer (2018) found that DRM lures and lures in a conjunction lure paradigm correlated and loaded on the same factor. This false memory factor was related to both WM and source monitoring. Importantly, and consistent with prior research, the relation between WM and false memories was mediated by source monitoring abilities. Thus, across a number of studies it seems that there are reliable individual differences in false memories from the DRM paradigm and susceptibility to these false memories is generally related to a number of different cognitive abilities including LTM and WM abilities. However, these relations are likely attributable to shared variance with source monitoring abilities which are critical for resisting lures in the DRM and intrusions more generally (see also Jonker, 2016; Lilienthal et al., 2015; Rose, 2013 for similar results).

Additional research has suggested that individual differences in false memories in the DRM are related to convergent (remote associates test performance), but not divergent (alternative uses test performance) thinking (Dewhurst, Thorley, Hammond, & Ormerod, 2011) or Field Dependence-Independence (Corson, Verrier, & Bucic, 2009). In addition to examining cognitive relations with false memories in the DRM, a number of studies have found that various personality measures correlate with susceptibility to false memoires (although see Salthouse & Siedlecki, 2007). As noted above, Winograd et al. (1998), Platt et al. (1998), and Wilkinson and Hyman (1998) all found relations between DRM lures and some aspects of personality. Likewise a number of studies have found that Need for Cognition is positively related to false memories in the DRM paradigm (Graham, 2007; Leding, 2011; Wootan & Leding, 2015). Ben-Artzi and Raveh (2016) have also found that aspects of perfectionism were related to false alarms in the DRM, with people more worried about the discrepancy between standards and performance exhibiting high false alarm rates. Sanford and Fisk (2009) found that extraverts were more likely to falsely recall than introverts. Thus, in addition to relations with cognitive abilities, some prior research has found that different aspects of personality are related to false memories in the DRM. Unfortunately, most of these studies did not include cognitive measures (such as source monitoring), so it is difficult to know whether cognitive abilities and personality account for shared or unique variance in predicting susceptibility to false memories in the DRM.

Although a number of studies have examined individual differences in false memories in the DRM, relatively little work has examined the extent to which these individual differences are related to other false memoires. As noted above, Lövdén (2003) found that different false memory paradigms correlated and loaded onto the same factor suggesting a common source of false memories. However, more recent research has suggested that false memories in the DRM are not necessarily related to false memories in other paradigms such as the misinformation effect. The misinformation effect refers to memory errors that occur as a result of misleading postevent information (e.g., Loftus, 2005). Several recent studies have found no relation between false memories in the DRM and the misinformation effect. For example, Ost et al. (2013) had 120 participants perform both DRM and a variant of the misinformation effect paradigm. Although both paradigms elicited false memories the correlations between the two paradigms were weak and near zero (see also Calvillo & Parong, 2016; Zhu et al., 2013). Thus, it does not seem to be the case that false memories in the DRM and the misinformation effect are related, and these results call into question whether there is a common source of individual differences in false memories. Clearly more research is needed to better examine the extent to which various indicators of false memories are related and can be accounted for by a single common factor.

Although the DRM and misinformation effect do not seem to be related, a number of studies have found individual differences in the misinformation effect. For example, Zhu et al. (2010a) found that the misinformation effect was negatively related to measures of intelligence, WM, perceptual abilities, and face recognition. In an analysis of the same dataset Zhu et al. (2010b) found generally weaker relations between the misinformation effect and aspects of personality, whereas an overall cognitive ability measure (a composite of the scores from Zhu et al., 2010a) correlated ($r = -.40$) with the misinformation effect. In another recent study, Calvillo (2014) found that a hindsight task, a WM task, and an embedded figures task were all negatively related to the misinformation effect, whereas personality measures were not. Thus, like the DRM, there seem to be robust individual differences in the misinformation effect which are related to various cognitive abilities. Future research is needed to better understand how these various cognitive abilities are uniquely and jointly related to the misinformation effect and to determine what underlying mechanism(s) is accounting for variation in the misinformation effect.

Prior research suggests that there are clear individual differences in the susceptibility to false memories and these individuals differences are related to a number of cognitive abilities (possibly due to source monitoring abilities). Likewise, individual differences in the misinformation effect are linked to a number of cognitive abilities, but it is currently unclear how/why these abilities are related. Theoretically one might assume that individual differences in source monitoring abilities would also be important for variation in the misinformation effect, but data are lacking in this regard. More research is needed to better clarify the nature of individual differences in the susceptibility to false memories.

Individual Differences in Testing/Retrieval Practice

The above reviews suggests consistent individual differences in situations where our memory system tends to fail. Here I examine whether there are individual differences in strengthening memories via retrieval practice (i.e., testing). A great deal of research has suggested that retrieval acts to strengthen and modify memories leading to heightened performance on subsequent memory tests. Specifically, the testing effect refers to the finding that LTM for items that were initially tested tends to be better than items that were initially restudied (Roediger & Butler, 2011; Roediger & Karpicke, 2006; Rowland, 2014). In a typical experiment participants are presented with TBR items for initial study. Next participants are either tested on the TBR items or they restudy the items. On a final memory test (typically after some delay) items that were initially tested tend to be remembered better than items that were restudied. This effect has been found in a number of paradigms, with different types of materials, and different populations. Furthermore, a great deal of recent research has suggested that the testing effect is critically important in educational contexts as a means of increasing learning and retention (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013).

Given the importance of testing and retrieval practice to educational contexts, a critical question is whether testing works for everyone. Early accounts suggested that testing does in fact occur for all individuals. For example, Pashler, McDaniel, Rohrer, and Bjork (2008), in arguing against learning styles, suggested that the testing effect "is not something that applies to only a small subset of learners but (as far as can be told) applies to all" (p. 117). This suggests that all individuals experience a testing effect. Here I examine three critical questions in terms of the testing effect. (a) Are there individual differences in testing? (b) Do all individuals show a testing effect? That is, as suggested by Pashler et al. (2008) does testing enhance retention for all participants? Are there some participants who do not show a testing effect? (c) Assuming there are individual differences in the testing effect, are these individual differences systematically related to other cognitive abilities?

Several developmental and aging studies have been done, suggesting that there is robust variation in the testing effect. For example, Bouwmeester and Verkoeijen (2011) examined children ($N = 131$; 7–13 year olds) and using latent class analysis found that two classes of children demonstrated testing effects (although one class of children demonstrated stronger testing effects). Interestingly, they found a third class of children whose testing effect was not significant. That is, in this group of children, testing did not lead to better memory than restudy. Thus, contrary to the speculation of Pashler et al. (2008) not all individuals demonstrated a testing effect. More recent evidence by Aslan and Bäuml (2016) similarly suggested that younger elementary students did not benefit from testing, but older elementary students did. In terms of aging, Tse, Balota, and Roediger (2010) found a negative correlation between testing and age when no feedback was present, but a positive correlation when feedback was present. Furthermore, in both experiments there were a large number of participants who demonstrated either no testing effect or a negative testing effect (i.e., greater performance following restudy compared with testing). Similar to the developmental work, these results suggest that there are clear age differences in testing and there are clearly some participants who do not necessarily demonstrate a testing effect.

Examining individual differences in undergraduate students, Brewer and Unsworth (2012) had participants ($N = 107$) perform a paired associates task in which some items were restudied and others were tested. Following a 24-hr delay participants took a final cued-recall test on all items. Brewer and Unsworth tested three possible hypotheses: (a) Testing provides general benefits across the ability range. That is, all participants benefit from testing and benefit to the same extent. (b) Testing allows the rich to get richer. High ability participants will benefit more from testing than low ability participants given their already superior cognitive abilities. (c) Testing homologizes memory across the ability range. Testing benefits low ability participants more than high ability participants because high ability participants are already performing maximally. Brewer and Unsworth found the standard testing effect (reliability = .50). Furthermore, Brewer and Unsworth found that 67% of participants demonstrated a positive testing effect, whereas 12% showed no testing effect and 21% demonstrated a negative testing effect. Examining relations with cognitive abilities, Brewer and Unsworth found that the magnitude of the testing effect was not related to WM or AC, but was related to both episodic LTM ($r = -.29$) and gF ($r = -.28$). Examining LTM and gF separately suggested that low LTM and low gF individuals demonstrated significant testing effects, but high LTM and high gF individuals did not. These results are most consistent with the notion that testing homologizes memory across the ability range by increasing retention for low ability individuals more than high ability individuals. Thus, results from this study seem to suggest that there are clear individual differences in the testing effect, not all individuals demonstrate a testing effect, and some (but not necessarily all) cognitive abilities are related to the testing effect.

Although the results from Brewer and Unsworth (2012) are encouraging, they are lessened by recent research which has failed to replicate some of the findings. Specifically, Pan, Pashler, Potter, and Rickard (2015) attempted to replicate the negative relation between testing and LTM abilities using the same tasks utilized by Brewer and Unsworth (2012) in two experiments. In their first experiment Pan et al. examined the relation between testing and LTM abilities in an online sample of participants ($N = 120$) and found no significant relation ($r = .15$). In a second experiment with a sample of undergraduate students ($N = 122$) from UC San Diego they again found no relation between the testing effect and LTM abilities ($r = .10$). Thus, unlike Brewer and Unsworth (2012) who found a negative relation, Pan et al. (2015) found nonsignificant positive relations. Note that Pan et al. did not report reliability estimates for the testing effect nor for the paired associates task from which the testing effect was derived, thus making it difficult to rule out the possibility that the differences could be due to poor reliability of the measure. Pan et al. suggested that differences in the composition of samples could have resulted in differences in the relation. Specifically, comparing performance on the different LTM tasks suggests that participants performed much better on most of the tasks in the Brewer and Unsworth (2012) study than in the Pan et al. study. Given this, Pan et al. suggested that Brewer and Unsworth's study was composed of relatively high-ability participants whereas their participants were more middle-to low ability participants. Pan et al. provided a descriptive psychometric model suggesting a curvilinear relation between the testing effect and LTM abilities in which both low and high ability individuals demonstrate little if any testing effects, whereas midrange LTM ability individuals demonstrate more robust testing effects. Thus, depending on the composition of the sample you could get a positive relation, a null relation, or a negative relation. Although this certainly makes sense and is a possible reason for the discrepant results, it is not at all clear why the relation between testing and LTM abilities is necessarily curvilinear rather than linear. Additionally, although there are clear differences in the scores on the LTM measures in each study, it is not clear that this necessarily reflects differences in the ability ranges for the samples. Specifically, in their Experiment 2 Pan et al. used participants from the Psychology pool at UC San Diego where the average SAT score for incoming students is 1291. Brewer and Unsworth (2012) similarly used participants from a Psychology pool at the University of Georgia where the average SAT score for incoming students is 1302. Thus, the two samples would seem to have very similar ability ranges. Furthermore, we have used the same LTM measures in a number of studies (with over 1,000 participants) with both undergraduate and community volunteers and the overall means are very similar to those reported in Brewer and Unsworth (2012). So, it is not at all clear why there were differences between the two studies not only in the different LTM measures, but also in the magnitude of the testing effect. Specifically, Brewer and Unsworth reported a testing effect around 6% whereas Pan et al. reported a testing effect of 19% in their Experiment 2. This difference in the size of the testing effect was largely attributable to differences in performance on the restudied items (M in Brewer & Unsworth = .45; M in Pan et al. = .36) rather than performance on the tested items (M in Brewer & Unsworth = .51; M in Pan et al. = .55).

Given Pan et al.'s reasoning of possible differences in the ability ranges for the samples across studies, it seems reasonable to combine the two samples, thereby widening the overall ability range and increasing the overall sample to better examine the relation between LTM abilities and the testing effect. Shown in Figure 14 is a histogram of the magnitude of the testing effect for the combined sample ($N = 349$). As can be seen, there are substantial individual differences in the testing effect and consistent with prior research not all participants demonstrate a positive testing effect. Specifically, 21% of the participants do not show a positive testing effect (17.2% demonstrate a negative testing effect and 3.8% demonstrate no effect).

Next, the correlation between LTM abilities and the magnitude of the testing effect was examined for the full distribution. The correlation was $r = -.19$ ($p < .001$), suggesting a negative relation between LTM abilities and the testing effect. Thus, combining samples from Brewer and Unsworth and Pan et al. to increase the range of abilities of the sample and increase the overall sample size resulted in a significant negative relation between LTM abilities and the testing effect.[5]

In another recent study, Robey (2018) attempted to replicate and extend these findings. Two experiments were conducted to examine relations between LTM, gF, strategy use, and variation in the testing effect. In both experiments Robey found a small testing effect ($M = .07$). Consistent with prior research, 71.4% of participants demonstrated a testing effect, 8.7% showed no testing effect, and 19.9% demonstrated a negative testing effect. Examining variation in strategy use demonstrated a negative relation with testing, suggesting that participants who use more beneficial strategies (visual imagery, sentence generation) were less likely to demonstrate a testing effect. This finding is consistent with Mulligan, Rawson, et al. (2018) who demonstrated that the negative testing effect typically occurs in higher ability participants and this is likely attributable to the fact that these participants are using better strategies particularly on restudied items. Robey also found

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[5] Given Pan, Pashler, et al.'s suggestion that the relation might be curvilinear, I also tested whether the relation was quadratic in nature. The quadratic effect was not significant ($\beta = .11$, $p = .17$). Thus, there was no evidence that the relation between LTM abilities and the testing effect may be nonlinear.

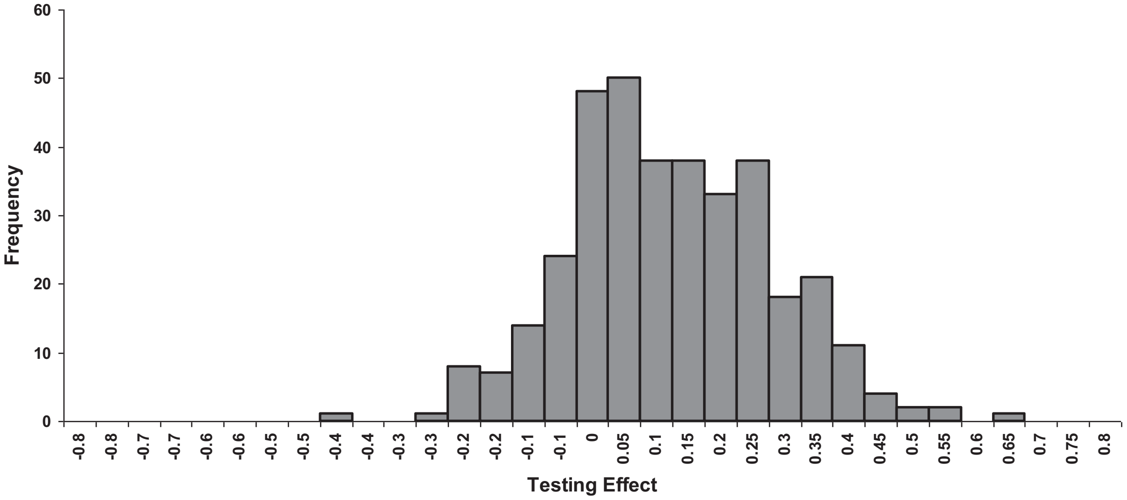

Figure 14. Frequency distribution of the Testing Effect. Combined data from Brewer and Unsworth (2012) and Pan et al. (2015).

a weak and significant negative correlation with gF. Examining relations with LTM abilities suggested a weak negative (and nonsignificant) correlation with testing. Again, suggesting that the relation between LTM abilities and testing is not very robust. However, combining data from Brewer and Unsworth (2012), Pan et al. (2015) and Robey (2018; despite differences in the exact methods) suggested that there is a negative correlation between LTM abilities and testing, $r = -.22$, $p < .001$, $N = 548$.[6] Future research is needed to better examine possible relations between individual differences in the testing effect and LTM abilities, the extent to which the relation is linear or nonlinear, and possible moderating factors such as length of delay, difficulty of items, sample composition, feedback, and other potentially important factors.

Similar inconsistent findings have been demonstrated for the relation between WM and the testing effect. As noted above, Brewer and Unsworth (2012) did not find a relation between testing and WM. Similarly, Wiklund-Hörnqvist, Jonsson, and Nyberg (2014) found that the testing effect did not interact with individual differences in WM in sample of 83 undergraduates. However, it should be noted that this was a between-subjects design in which half the participants restudied items and the other half were tested. Thus, there is no real indication of the size of the testing effect for each individual. Tse and Pu (2012) found a small (but not significant) positive relation between testing and WM. Interestingly, WM interacted with test anxiety in predicting the testing effect. Specifically, for low WM participants test anxiety was negatively related to the testing effect, but for high WM participants there was no relation, suggesting that it may be important to examine test anxiety as a moderator of individual differences in the testing effect. More recently Agarwal, Finley, Rose, and Roediger (2017) found a negative relation between WM and the testing effect ($r = -.42$), but this only occurred with a significant delay (2 day delay) and with feedback. No relations were found with a 10 min delay or without feedback. These results suggest that sometimes there is a relation between WM and individual differences in the testing effect. Like the relations with LTM abilities, it is clear that future research is needed to examine the robustness of these relations and what factors moderate the relation.

In another recent study, Minear et al. (2018) examined the relations between WM, gF, and gC with the testing effect. Minear et al. had undergraduate students ($N = 343$) perform a paired associates task in which some items were restudied and others were tested. Half of the items were easy pairs and the other half were difficult pairs. Following a 2 day delay participants took a final cued-recall test for all items. Minear et al. found a significant testing effect ($M = .07$). Furthermore, Minear et al. found that 61% of participants demonstrated a positive testing effect, 8% had no testing effect, and 31% demonstrated a negative testing effect. Also consistent with prior research, Minear et al. found that reliability estimates for the testing effect were not particularly great for both easy (.45) and hard (.57) items. Examining relations between the cognitive ability measures and the overall testing effect suggested no significant relations. Importantly, however, examining the relations as a function of item difficulty suggested that both gF and gC measures were positively correlated with the testing effect for difficult items, but were negatively correlated for easy items. Thus, item difficulty moderated the relation. This is an important finding suggesting that item level analyses distinguishing easy versus difficult items are likely critical for examining relations between testing effects and abilities. Minear et al. also examined differences between positive and negative testers. They found that negative testers were more likely to self-test whereas positive testers were more likely to rely on shallow encoding processes. Thus, examining differences in strategies (see also Robey, 2018) will also be important in future research for examining individual differences in testing. In terms of negative testers, Minear et al. found a negative correlation between the testing effect and gF ($r = -.26$), suggesting that high gF individuals

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[6] Thanks to Timothy Rickard and Alison Robey for providing me with their data.

benefitted more from restudy than testing. This suggests that some high-ability participants demonstrate negative testing effects (i.e., a greater benefit for restudy than for testing) and Minear et al. (2018) suggest this could be linked to individual differences in strategy use consistent with findings by Mulligan, Rawson, et al. (2018) and Robey (2018).

Collectively, research examining individual differences in the testing effect suggests that (a) there are indeed large and robust individual differences in the size of the testing effect. (b) Not all participants demonstrate a testing effect, and in fact a large percentage demonstrate negative testing. Thus, contrary to the conjecture of Pashler et al. (2008) there are in fact subsets of participants who do not necessarily benefit more from testing than from restudy. For example, some recent research has suggested that individuals with ADHD do not necessarily benefit from testing (Dudukovic, Gottshall, Cavanaugh, & Moody, 2015; although see Knouse, Rawson, Vaughn, & Dunlosky, 2016 for a demonstration of similar testing effects in participants with ADHD and controls). Note this does not mean that these individuals will never show a benefit from testing, but rather that in some situations and some paradigms some individuals benefit more from restudy than from testing. And (c) individual differences in various cognitive abilities tend to be related to individual differences in the magnitude of the testing effect, but these relations are inconsistent and are potentially moderated by factors such as the ability range of the sample, difficulty of the items, presence or absence of feedback, delay length, and potentially other factors. Future research is needed to more thoroughly examine relations between individual differences in the benefits of retrieval practice and their relation with other cognitive abilities and the role of various potential moderating factors.

Individual Differences in General Retrieval Abilities

The current review has primarily focused on LTM abilities derived from list-learning tasks and thus has primarily focused on Learning Efficiency Factors of the broader Glr/LTM factor (McGrew, 2009; Schneider & McGrew, 2012). However, it was also noted that other LTM abilities (Glr) such as General Retrieval abilities (Retrieval Fluency) are also important (McGrew, 2009; Schneider & McGrew, 2012). Therefore, individual differences in General Retrieval abilities are also reviewed. Thurstone (1938) was perhaps the first to recognize that fluency tasks tended to correlate and load on a distinct factor. In these verbal fluency tasks participants are required to generate exemplars from some specified category or cue in a limited amount of time (typically ranging from 30 s to several minutes). Based on an exhaustive review of the literature up to that point, Carroll (1993) identified 121 data sets that identified different Idea Production factors (i.e., Fluency factor), including lower order factors of Ideational Fluency, Naming Facility, Associational Fluency, Expressional Fluency, Word Fluency, Sensitivity to Problems, Originality/Creativity, Figural Fluency, and Figural Flexibility. Importantly, several studies have found that these different fluency tasks tend to correlate well with one another and load onto the same factor. Furthermore, when there are enough measures to form different first-order factors, a higher-order General Retrieval factor can be found. For example, consider a study by Silvia, Beaty, and Nusbaum (2013). In this study participants ($N = 131$) performed 16 different fluency tasks consisting of word fluency tasks (e.g., list as many words starting with CON as possible), associational fluency tasks (e.g., list synonyms for good), associative flexibility (e.g., list words related to the prior word starting with the word music), ideational fluency (e.g., list occupations), letter fluency (e.g., list words beginning with F), and dissociative ability (e.g., list random unrelated words starting with baby). Silvia et al. specified six Fluency factors and found that all of the factors were correlated with one another (*r*s ranging from .41–.92). Importantly, specifying a single higher-order General Retrieval factor led to a good fit of the data with each of the lower order factors loading onto the higher-order factor. Furthermore, the higher-order General Retrieval factor was correlated with both gC ($r = .36$) and typing speed ($r = .29$). Thus, there is ample evidence that there are systematic individual differences in the ability to rapidly retrieve information from LTM (General Retrieval ability) and a clear factor structure differentiated by different retrieval requirements.

Not only has prior research demonstrated that fluency tasks correlate well with one another, but the total number of words retrieved in these tasks tends to correlate with a number of other cognitive abilities at the zero-order level. For instance, several studies have demonstrated relations between fluency scores and performance on various episodic LTM tasks (e.g., Cohen, 1984; Hakstian & Cattell, 1978; Hedden, Lautenschlager, & Park, 2005; Hedden & Yoon, 2006; Ruff, Light, Parker, & Levin, 1997; Unsworth & Spillers, 2010a) and WM tasks (e.g., Fisk & Sharp, 2004; Fournier-Vicente, Larigauderie, & Gaonac'h, 2008; Hedden et al., 2005; Hedden & Yoon, 2006; Hills & Pachur, 2012; Rosen & Engle, 1997; Ruff et al., 1997; Schelble, Therriault, & Miller, 2012; Shipstead, Harrison, & Engle, 2016; Unsworth, 2017; Unsworth, Brewer, & Spillers, 2013; Unsworth, Miller, et al., 2009; Unsworth & Spillers, 2010a; Unsworth et al., 2011; Unsworth, Spillers, & Brewer, 2012). Total scores on verbal fluency tasks are related to vocabulary and overall gC in a number of studies (e.g., Ardila, Galeano, & Rosselli, 1998; Ardila, Pineda, & Rosselli, 2000; Hakstian & Cattell, 1978; Hedden et al., 2005; Hughes & Bryan, 2002; Jewsbury & Bowden, 2017; Ruff et al., 1997; Unsworth et al., 2011) and are related to processing speed (e.g., Ardila et al., 1998; Fisk & Sharp, 2004; Hakstian & Cattell, 1978; Hedden et al., 2005; Hedden & Yoon, 2006; Hughes & Bryan,

Figure 15 (*opposite*). (a) Confirmatory factor analysis with speed of processing (Speed), working memory (WM), long-term memory (LTM), vocabulary (Vocab), and Fluency factors. LC = letter comparison; PC = pattern comparison; DS = digit symbol; Rspan = reading span; Cspan = computation span; Lspan = line span; Rotspan = rotation span; Shipley = Shipley vocabulary; Syn = synonym vocabulary; Ant = antonym vocabulary; FR = free recall 1; FR 2 = free recall 2; PA 1 = paired associates 1; PA 2 = paired associates 2; Rec 1 = recognition memory 1; Rec 2 = recognition memory 2; F Flu = F letter fluency; A Flu = A letter fluency; S Flu = S letter fluency. (b) Structural equation model with speed of processing (Speed), working memory (WM), long-term memory (LTM), vocabulary (Vocab) factors predicting Fluency. Solid paths are significant at the $p < .05$ level. Data from Hedden et al. (2005).

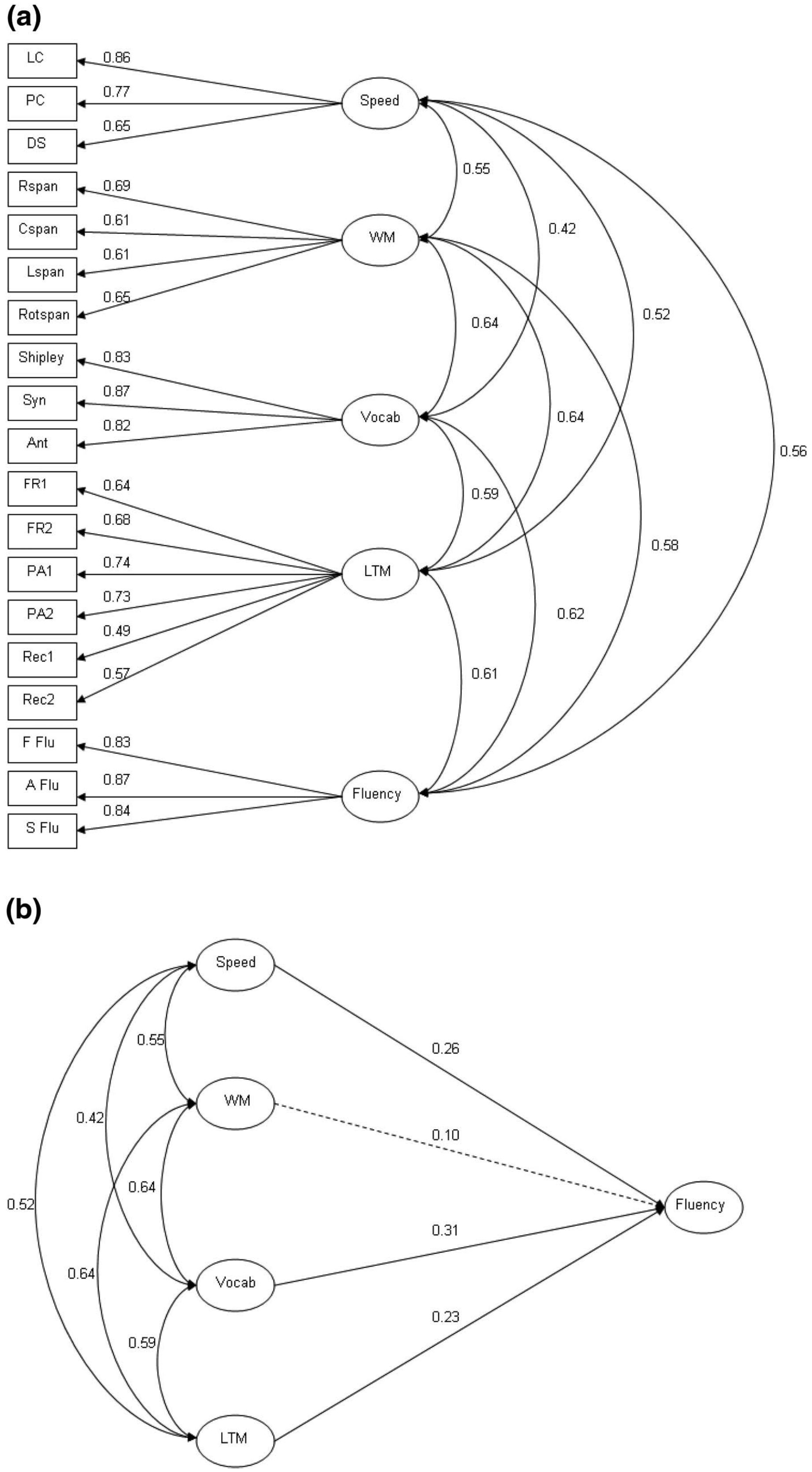

Figure 15 (*opposite*).

2002; Jewsbury & Bowden, 2017; Unsworth et al., 2011). Furthermore, although the evidence is somewhat mixed, there is evidence for a relation between measures of AC and total number of words generated on verbal fluency tasks (e.g., Ardila, Pineda, & Rosselli, 2000; Fisk & Sharp, 2004; Hedden & Yoon, 2006; Shipstead et al., 2016; Unsworth, Miller, et al., 2009; Unsworth & Spillers, 2010a; Unsworth et al., 2011; but see Fournier-Vicente, Larigauderie, & Gaonac'h, 2008; Hughes & Bryan, 2002). Finally, there also seems to be a relation between gF and total verbal fluency scores (e.g., Shipstead et al., 2016; Unsworth, Miller, et al., 2009; Unsworth & Spillers, 2010a; but see Hakstian & Cattell, 1978). Scores on verbal fluency tasks also have been found to relate to arithmetic abilities (Ardila et al., 1998) shifting abilities (Fournier-Vicente et al., 2008; Hedden & Yoon, 2006), and various personality correlates (Unsworth, Miller, et al., 2009). Thus, total scores on verbal fluency tasks seem to be related to a number of important cognitive constructs at least at the zero-order correlation level.

Additional research has shown that latent General Retrieval factors tend to correlate with other latent factors of cognitive abilities. For example, Hakstian and Cattell (1978) found that a General Retrieval factor correlated with gC ($r = .30$), perceptual speed ($r = .30$), and LTM ($r = .22$), but not with gF ($r = -.05$). In two studies, Hedden and colleagues (Hedden et al., 2005; Hedden & Yoon, 2006) provided evidence that fluency tasks load on a common factor which is related to other important cognitive constructs including LTM, WM, AC, processing speed, and vocabulary. Similarly, Fournier-Vicente et al. (2008) found that a General Retrieval factor correlated with latent factors of WM, AC, and shifting and Unsworth et al. (2009) found that a General Retrieval factor correlated with latent factors of WM, AC, and gF.

Based on this prior work, Unsworth et al. (2011) examined whether there are differences between semantic (name as many animals in 60 s) and letter (name as many words that begin with the letter F in 60 s) fluency tasks and how they are related to other cognitive abilities. Unsworth et al. found that the fluency tasks loaded onto a single factor and this latent fluency factor was significantly related to WM ($r = .55$), vocabulary ($r = .36$), processing speed ($r = .27$) and AC ($r = .29$). Importantly, examining these relations with structural equation modeling suggested that only WM and vocabulary accounted for unique variance in fluency scores. The relation between AC and fluency was largely mediated by WM. Thus, although several cognitive abilities were related to overall fluency scores, WM and vocabulary (and to a lesser extent processing speed) seemed to be particularly important for General Retrieval abilities.

To further examine relations between verbal fluency and cognitive abilities, data from Hedden et al. (2005) were reanalyzed. As noted above, in this study 345 participants performed three different fluency tasks, along with multiple measures of processing speed, WM, vocabulary, and LTM. First a confirmatory factor analysis was specified in which the fluency measures loaded onto one factor and this factor was allowed to correlate with the other cognitive ability factors. The overall fit of the model was acceptable, $\chi^2(139) = 268.99$, $p < .001$, RMSEA = .05, NNFI = .98, CFI = .98, SRMR = .05. As shown in Figure 15a, the fluency measures loaded strongly onto the fluency factor and this factor was strongly correlated with all of the other factors consistent with prior research. Next, a structural equation model was specified to examine how the different cognitive abilities would predict individual differences in fluency. The overall fit of the model was acceptable, $\chi^2(139) = 268.99$, $p < .001$, RMSEA = .05, NNFI = .98, CFI = .98, SRMR = .05. As shown in Figure 15b, speed of processing, vocabulary, and LTM predicted unique variance in the fluency factor accounting for 53% of the overall variance in General Retrieval abilities (see supplemental materials for an additional model).

Prior research suggests that performance on fluency tasks is well described by a two-stage search process in which in the first stage participants search for overall categories/contexts (e.g., different categories of animals including farm animals, jungle animals, etc.) and then in the second stage participants search for specific items within the categories/contexts (cow, pig, chicken, etc. for farm animals; Bousfield & Sedgewick, 1944; Graesser & Mandler, 1978; Gruenewald & Lockhead, 1980; Herrmann & Pearle, 1981; Walker & Kintsch, 1985; Williams & Hollan, 1981; Wixted & Rohrer, 1994). Based on this idea, Troyer et al. (1998) proposed a two-component model of verbal fluency that suggested that performance relies on both clustering and switching. Clustering refers to the generation of words within particular subcategories as defined by the current task, whereas switching, however, refers to the generation of new subcategories from which items are subsequently sampled (see Mayr, 2002; Mayr & Kliegl, 2000 for a different view). A number of studies have examined the extent to which different indicators of clustering and switching are related to various cognitive abilities. For example, Rosen and Engle (1997) found that high WM individuals recalled more animal names, recalled more clusters of animal names, had larger cluster sizes, and recalled at a faster rate than low WM individuals. Unsworth et al. (2013) had high and low WM participants recall animal names for 5 min and after the task participants were provided with their responses and had to indicate their own clusters (see also Buschke, 1977). Unsworth et al. found that high WM individuals recalled more items, and more clusters of items than low WM individuals, but there were no differences in the overall size of clusters. Similar results were also found in Unsworth et al. (2012) when retrieving friends names (see also Hills & Pachur, 2012). Furthermore, in a second experiment, Unsworth et al. (2013) found that by providing participants with category cues and eliminating the requirement to self-generate cues and switch between cues, WM differences were eliminated. These results suggest that a critical component to variation in verbal fluency (and hence General Retrieval abilities), is the ability to self-generate cues and switch between cues.

Further evidence distinguishing between clustering and switching abilities comes from Hughes and Bryan (2002), who found that vocabulary was related to overall number of words generated as well as number of switches, and processing speed was related to switching (neither clustering nor switching was related to any of the putative measures of executive functioning). More recently, Unsworth et al. (2011) found that clustering was correlated with WM and vocabulary, but not with processing speed or AC. Switching abilities, however, were related to WM and processing speed, but not to vocabulary or AC. Switching and clustering were negatively correlated ($r = -.49$). These results suggest that the ability to self-generate cues (and switch between cues) and the ability to access and retrieve associatively related items (clusters) are both important aspects of General Retrieval abilities. Furthermore, these abilities (although related) are somewhat distinct in that some participants will demonstrate superior performance because they are able to generate many different cues leading to accessing many different clusters, whereas other participants might demonstrate superior performance because once a cluster is accessed they have extensive background knowledge (gC and vocabulary) and greater associative links leading to larger cluster sizes. Deficits in either ability will lead to reduced performance and deficits in General Retrieval abilities.

Examining recall latency and interresponse times in fluency tasks can also be informative in terms of examining the dynamics of the search process and how this may change as a function of individual differences. A fairly standard finding is that individuals who retrieve more items tend to reach asymptotic levels of recall at a slower rate than individuals who retrieve fewer items (e.g., Johnson, Johnson, & Mark, 1951; this is also true for various neuropsychological conditions such as Alzheimer's, Rohrer et al., 1999).[7] Similar to free-recall tasks, high ability participants tend to have faster interresponse times than low ability participants (e.g., Rosen & Engle, 1997; Unsworth et al., 2012, 2013). This suggests that a critical aspect of General Retrieval abilities is the ability to efficiently search LTM (episodic, semantic, and autobiographical LTM). Future research is needed to better examine individual differences in search dynamics across various tasks (free recall, fluency) and how they are related to other cognitive abilities.

Individual differences in General Retrieval abilities are a critical part of overall individual differences in LTM. General Retrieval abilities (indexed with fluency tasks) are correlated with several cognitive abilities. Crucial to General Retrieval abilities is both the ability to self-generate cues (and switch between cues) and the ability to retrieve items from clusters based on shared item characteristics. Understanding individual differences in the dynamics of searching LTM will be critical for understanding overall variation in General Retrieval abilities.

Individual Differences in Strategies

Although it seems clear that there are individual differences in various aspects of LTM, it is also clear that individuals differ in the strategies they use to perform LTM tasks. For example, Atkinson and Shiffrin (1968; see also Nelson & Narens, 1990; Reitman, 1970) noted that their framework "emphasized the role of control processes—processes under the voluntary control of the subject such as rehearsal, coding, and search strategies. It was argued that these control processes are such a pervasive and integral component of human memory that a theory which hopes to achieve any degree of generality must take them into account" (p. 191; see also Benjamin, 2008; Hintzman, 2011). Thus, understanding individual differences in strategies during encoding and retrieval should not only provide us with a better understanding of what is occurring during a typical laboratory memory experiment, but understanding individual differences in strategies should also provide us with an overall better understanding of variation in LTM abilities.

Prior research has shown that effective strategies such as interactive imagery and sentence generation lead to higher levels of recall than ineffective strategies such as passive reading or rote repetition (Bower, 1972; Richardson, 1998). Furthermore, a great deal of empirical work has demonstrated that effective encoding strategy use correlates strongly with overall recall performance (Martin, Boersma, & Cox, 1965; Richardson, 1998) and partially accounts for age differences in memory performance (Hertzog & Dunlosky, 2004). In particular, it is thought that strategies like imagery and sentence generation are effective because they allow for the use of mediators to help associate items in tasks like paired-associates learning. Prior research has demonstrated strong relations between effective encoding strategies and performance on free recall, paired associates, source monitoring, and WM tasks (e.g., Bailey, Dunlosky, & Kane, 2008; Dunlosky, Hertzog, & Powell-Moman, 2005; Hertzog, Dunlosky, & Robinson, 2007; Hertzog & Dunlosky, 2004; Hertzog, McGuire, & Lineweaver, 1998; Kuhlmann & Touron, 2012; Lachman & Andreoletti, 2006; Richardson, 1978; Saczynski, Rebok, Whitfield, & Plude, 2007: Unsworth, 2016b; Wang, 1983), although it should be noted that in some contexts high ability participants demonstrate more rehearsal than low ability participants, leading to differences in recall (Fagan, 1972; Unsworth & Spillers, 2010b). Examining encoding strategies in free recall, Unsworth (2016b) found that both effective strategy use ($r = .64$) and ineffective strategy use ($r = -.26$) correlated with free recall performance and were uncorrelated with each other ($r = .01$). Furthermore, effective and ineffective strategy use along with a number of other variables accounted for 89% of the variance in recall performance (effective strategy use accounted for approximately 14% unique variance and ineffective strategy use accounted for approximately 5% unique variance). As noted by Hertzog and Dunlosky (2004) "individual differences in strategic behavior are substantial and critical for understanding associative memory" (p. 223).

In addition to demonstrating that encoding strategies are related to memory performance on the task on which both are measured, other studies have demonstrated that strategy use is related to other cognitive abilities as well. Hertzog et al. (2007) had more than 300 participants perform a paired associates task and report what strategies they used to associate the pairs. Hertzog et al. found that strategy reports correlated strongly with paired associates recall performance ($r = .74$), suggesting that half of the variance in recall performance was due to effective strategy use. Furthermore, Hertzog et al. found that effective strategy use correlated with a variety of cognitive ability measures (*r*s ranging from .25–.49). Overall similar results were also found when examining strategy reports from free recall.

Given the finding that strategy use correlates with overall performance, the next key question is what aspect(s) of strategy use is related to performance. Specifically, Dunlosky, Hertzog, and col-

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[7] Note that this finding is actually opposite of what is typically found in free recall in which high-ability participants typically reach asymptotic levels of recall faster than low ability individuals. This is because in fluency tasks the goal is to retrieve as many items as possible that match the cue (e.g., animals). Those individuals who retrieve more items will tend to keep retrieving items throughout the recall period, whereas individuals who retrieve fewer items will tend to reach asymptotic levels sooner owing to not being able to generate more items. In free recall tasks, however the goal is to retrieve as many items as possible that match the cue and are constrained by the current list (e.g., animals only presented on the most recent list). Recalling all items related to the cue could lead to proactive interference if other animals were presented on prior lists or to a large number of extra-list intrusions (animals not presented at all). Thus, it is critical in free recall tasks to constrain the search to the current context.

leagues (Dunlosky & Hertzog, 1998; Dunlosky et al., 2005; Hertzog & Dunlosky, 2004) have examined the possible roles of mediator production and mediator retrieval in terms of individual and age differences in the relation between encoding strategies and memory performance. Mediator production refers to the notion that low ability individuals are less likely to produce effective mediators and strategies during encoding than high ability individuals (Hertzog & Dunlosky, 2004). In line with this hypothesis, Dunlosky and Hertzog (1998) had participants self-report what strategy, if any, they used for each pair of items and found that high ability individuals were more likely to report using imagery than low ability participants. In particular, they found that vocabulary scores predicted imagery production which in turn predicted overall recall scores and this occurred for both pairs of related and unrelated items. These results are consistent with prior research suggesting that gC is an important predictor of paired associates recall (Kyllonen & Tirre, 1988; Kyllonen et al., 1991), but suggest that this relation may be because having more knowledge allows for the creation of more or better mediators (see also Dunlosky et al., 2005). Thus, there is some evidence that mediator production is an important contributor to individual differences in associative memory.

Mediator retrieval refers to whether or not the mediator that was generated at study can be effectively recalled during retrieval. It is possible that low ability participants can produce effective mediators at encoding, but during test they cannot recall the mediators resulting in forgetting (Hertzog & Dunlosky, 2004). To examine this, Dunlosky et al. (2005) had participants perform a paired associates task and after attempting to recall each pair, participants were prompted to recall the mediator that they used to study the pair. Dunlosky et al. found that when participants recalled the mediator they typically recalled the correct item. However, recall was substantially lower when participants could only recall part of the mediator, could not recall the mediator at all, or recalled the wrong mediator. Importantly, they found that mediator recall was substantially related to individual differences in recall performance ($r = .75$). Furthermore, they found that mediator recall accounted for substantial unique variance in recall performance. Of course this result could be partially attributable to the fact that those with better recall abilities are more likely to recall the items on the list as well as recall the mediators. In all, 66% of the variance in paired associates recall was accounted for by a number of variables (age, processing speed, vocabulary, mediator recall, mediator production), with approximately half of that variance being attributable to individual differences in mediator retrieval. Thus, a key component to effective strategy use is the ability to actually recall what mediators were created during study.

Other factors also seem important in accounting for individual differences in encoding strategies and their influence on overall recall performance. For example, Hertzog et al. (1998) found that measures of strategy use, memory self-efficacy, and perceived control over memory were all related to performance on a free-recall task. Overall knowledge of encoding strategies also seems important. In the Hertzog et al. (2007) study mentioned previously, participants also completed a questionnaire to assess knowledge of the effectiveness of particular strategies. Hertzog et al. found that strategy knowledge predicted overall effective strategy use. Those participants who had prior knowledge of what strategies are most effective for learning were more likely to attempt to use those strategies during encoding. Furthermore, knowledge of the effectiveness of various encoding strategies likely comes about from actually trying and successfully using those strategies resulting in updating of strategy knowledge as a function of practice (Hertzog, Price, & Dunlosky, 2008; Hertzog, Lövdén, Lindenberger, & Schmiedek, 2017). Other important strategic factors are also likely important during encoding including variation in study time allocation, strategic encoding processes linked to the value of the items, and item selection during encoding (Castel et al., 2011; Dunlosky & Thiede, 2004; Robison & Unsworth, 2017; Unsworth, 2016b). Individual differences in each have been demonstrated and been shown to be related to overall variation in memory performance. Collectively prior research suggests that normal variation in the use of effective strategies is a potent indicator of individual differences in memory performance.

Strategies during retrieval are also important, with a number of studies finding that participants utilize a number of different retrieval strategies that are tailored to the specific retrieval task and that these strategies tend to change during the retrieval period (Gronlund & Shiffrin, 1986; Unsworth, Brewer, et al., 2014; Walker & Kintsch, 1985; Whitten & Leonard, 1981; Williams & Hollan, 1981). Furthermore, there are large individual differences in retrieval strategies that are linked to overall performance. For example, Schelble, Therriault, and Miller (2012) had participants name animals and then fill out a questionnaire regarding the various search strategies they used to perform the retrieval task. Schelble et al. found that participants reported a number of different strategies with the most common being environments, locations, classification, animals that live with humans, and personally relevant animals. Schelble et al. (2012) additionally found that the classification and environment strategies tended to correlate with overall retrieval levels as did a measure of WM. Similarly, Unsworth et al. (2013) found that high WM individuals reported using a knowledge based strategy more often than low WM individuals and low WM individuals more often reported using no particular strategy. In a recent follow-up study, Unsworth (2017) had 276 participants perform a fluency task and indicate what strategies they used. Consistent with prior research, reported strategy use correlated with the total number of items retrieved with semantic and knowledge-based strategies correlating positivity and rhyme, size, and no strategies correlating negatively with the total number of items retrieved. Additionally, during the retrieval task, half of the participants were randomly presented with thought probes asking them to indicate which strategies they had just been using to recall items. Thus, rather than relying on retrospective reports following the task, here participants were queried in a more online fashion. Unsworth found that participants who reported using a semantic strategy tend to retrieve more animals ($r = .37$), whereas participants who indicated not using a strategy tended to retrieve fewer animals ($r = -.18$.). Similar results were obtained in second experiment with additional fluency measures. Like variation in encoding strategies, variation in retrieval strategies are a major source of normal variation in the performance of various memory tasks.

Integrating Individual Differences in LTM in a General Framework of Memory

The present review has demonstrated that there are substantial individual differences in LTM abilities and this variation is related to other cognitive abilities. Here individual differences in LTM are integrated into a general framework of memory based on prior research which has suggested that individual differences in LTM likely arise from multiple sources. For example, in a review of the field MacLeod (1979) suggested that individual differences in memory could be understood in terms of a general dual-store model of memory. In this conceptualization, individual differences in memory could arise as a result of differences in the capacity of WM, differences in attention allocation to items, differences in the variety and effectiveness of various control processes, as well as differences in the ability to use cues to guide retrieval from LTM (see Carroll, 1974 for similar views). Additionally, in their book on Human Memory, Zechmeister and Nyberg (1982) devoted a chapter to individual differences in memory and suggested that these differences likely arose from variation in (a) basic mechanistic processes, (b) knowledge of voluntary encoding strategies, (c) degree of topic-related knowledge, and (d) metamemory. More recently Unsworth (2009b) suggested that individual differences in recall were attributable to differences in the ability to encode items, differences in the ability to use cues to focus the search on only relevant items, and the ability to monitor the products of retrieval. Clearly all of these accounts suggest that individual differences in memory likely arise from multiple sources and are unlikely to be due to a single source. Furthermore, these different accounts all suggest the need to place individual differences findings in terms of overall theories of LTM. To place prior research into context and to guide future research in individual differences in LTM, we can rely on Nelson and Narens' (1990) metamemory framework. Note that it is beyond the scope of the current paper to present a grand theory of individual differences in LTM abilities. Rather, the current discussion is merely a way to integrate individual differences in LTM with current theoretical frameworks of memory to understand this variation and to direct future research. As noted throughout, individual differences in LTM likely reflect variation in a number of different components. Shown in Figure 16 is an adaption of Nelson and Naren's framework based on more recent updates from Dunlosky, Serra, and Baker (2007) and Bjork, Dunlosky, and Kornell (2013). In this framework aspects of memory and metamemory are integrated at all phases with various monitoring and control processes influencing how we encode, store, and retrieve information from LTM. From an individual differences perspective it is likely that there is normal variation in all of these processes which result in variation in performance on a wide array of memory tasks.[8]

During encoding it is likely that these monitoring and control processes are at work and that individuals vary in how effectively these processes operate. It is likely that individuals differ in how strongly information is encoded (based on the amount of attention that is allocated to encoding activities) leading to differences in subsequent remembering. Prior research also strongly suggests that individual differences in LTM abilities are related to variation in encoding strategies (selection of kind of processing). This variation includes not only differences in what strategies are chosen for encoding, but also likely variation in the ability to carry out those strategies and variation in the ability to update knowledge of which strategies are effective. Variation in item selection is also a likely important source of variation in terms of deciding which items to study and which items to not study along with potentially how those items are studied. Decisions regarding how items are selected for study will impact overall performance and there are likely important individual differences in item selection (Dunlosky & Thiede, 2004). Decisions reflecting the termination of study (or study time allocation) are also a likely important source of variation. Finally, individual differences in the monitoring processes that are utilized during encoding will not only be related to overall memory performance, but will also interact in important ways with the control processes that are employed during encoding. Thus, individual differences in monitoring and control processes that are engaged in during encoding along with potential differences in how strongly items can be encoded likely play an important role in determining overall individual differences in performance on a variety of LTM tasks.

In terms of retrieval, individual differences during self-directed search are a likely important source of variation (e.g., Unsworth, 2009b, 2017). During search participants must devise an overall retrieval plan. This retrieval plan can include decisions about whether to search, how the search will be guided (what strategies to use), what cues are used to search and what combinations cues are used to search (cue elaboration), how specific the cues are (cue-specification), how cues are updated and search strategies are changed, as well as search termination decisions (Raaijmakers & Shiffrin, 1980). Decisions and abilities at each phase of the search process will be important for overall memory performance. Prior research suggests that there are substantial individual differences in retrieval strategies and updating/switching retrieval strategies within and between tasks. Furthermore, there are likely differences in the specificity of the cues. In free recall participants typically rely on temporal-contextual cues, but some individuals may be better able to encode and store contextual information and use contextual cues to focus the search than other individuals (Sahakyan, Abushanab, Smith, & Gray, 2014; Unsworth, 2007b, 2009b). Thus, participants might be using the same general cue and strategy, but differ in the specificity of the cues resulting in differences in how focused the search is. Similarly, individuals likely differ in how well they can reinstate encoding contexts at retrieval. This ability will be important not only in general episodic memory tasks that rely on contextual retrieval, but also in situations where it is important to remember what encoding strategies where used during study. Once items are retrieved, monitoring processes are needed to determine if the items are correct (or an intrusion) based on source monitoring processes and then judge overall confidence in the retrieved items. Finally, following various retrieval attempts, decisions will have to be made regarding whether to terminate or continue searching. Prior research has suggested a number of factors are involved in search termination decisions (Dougherty & Harbison, 2007; Harbison et al., 2009; Unsworth, Brewer, & Spillers, 2011c), and there are individual differences in search termination decisions. For example, Dougherty and Harbison (2007) found that individual differences in decisiveness (but not WM) were related to search termination. Like encoding, a number of monitoring and control processes operate during retrieval and there are likely substantial and important individual differences in each of these. Future research is needed to better examine these potential sources of individual differences.

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[8] Individual differences in consolidation processes occurring during sleep are also likely important (Fenn & Hambrick, 2012, 2015).

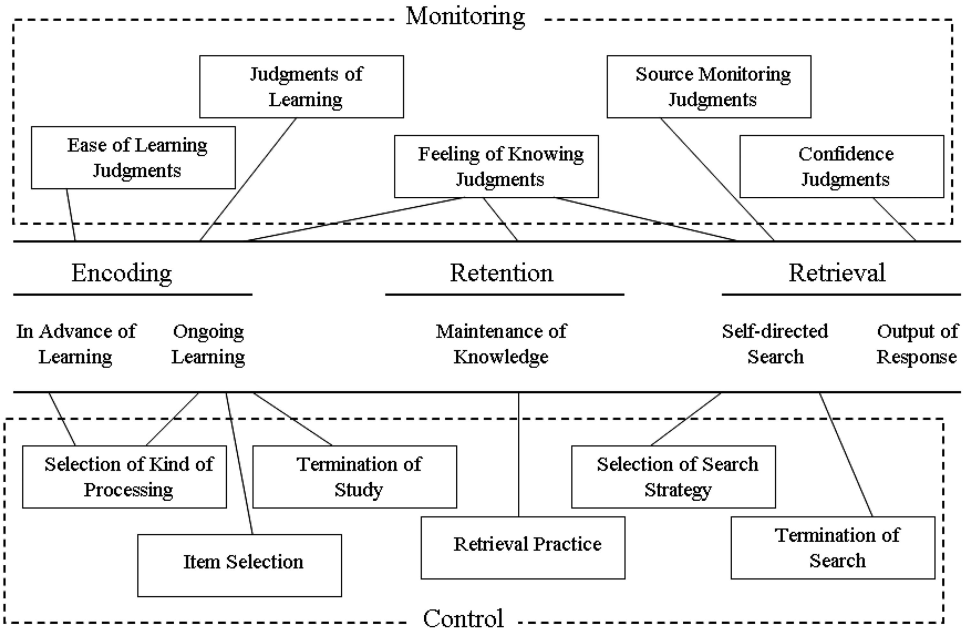

Figure 16. Nelson and Narens' (1990) metamemory framework. Based on adaptions from Dunlosky et al. (2007) and Bjork et al. (2013).

There are also a number of important general factors that are likely important sources of individual differences in LTM abilities. For example, overall differences in the ability to allocate attention to the task at hand and prevent task disengagement are also a likely source of individual differences in performance on various LTM tasks. Those individuals who can increase (and maintain) attention to items at encoding should encode those items better than individuals who cannot increase the allocation of attention (intensity) at encoding, leading to differences in subsequent performance. Indeed, Ebbinghaus (1885/1964) noted that "very great is the dependence of retention and reproduction upon the intensity of the attention and interest which were attached to the mental states the first time they were present" (p. 3). One way of examining this notion is to use pupillometry which has been shown to track the cognitive demands of a task (Beatty & Lucero-Wagoner, 2000; Kahneman, 1973; Kahneman & Beatty, 1966). For example, Miller, Gross, and Unsworth (2017) found that when words were presented during encoding in a delayed free-recall task the pupil dilated during the encoding period and this changed across serial positions. Importantly, Miller et al. found that individual differences in pupil dilation during encoding were related to overall performance (*r*s of .18 and .22) and accounted for unique variance in memory performance over and above that accounted for by individual differences in WM and strategy use. Thus, there is some evidence that individual differences in the ability to allocate attention during encoding are important for individual differences in LTM. Furthermore, individual differences in fluctuations (or lapses) of attention are another important source of variation in memory performance such that those individuals who experience more fluctuations of attention will likely not encode information as well as individuals who can consistently maintain their attention on task. Indeed, early work by Ebbinghaus (1885/1964) suggested that fluctuations in attention were important source of fluctuations in performance (see also Maillet & Rajah, 2013; Smallwood et al., 2003). Given strong relations between attention control and LTM abilities, it is likely that variation in the overall allocation and consistency of attention during encoding and retrieval are important contributors to individual differences in LTM. Furthermore, a great deal of prior research has suggested that motivation and interest are important contributors to performance and important sources of individual differences in addition to overall abilities (Kanfer, 1990; Kanfer & Ackerman, 1989). For example, prior research from our laboratory has found that individual differences in motivation and interest are strongly related to performance on reading comprehension (Robison & Unsworth, 2015; Unsworth & McMillan, 2013) and attention control tasks (Robison & Unsworth, 2018) independently of WM abilities and this variation in motivation and interest is related to variation in mind-wandering. This could be a major factor in LTM task as well. Finally, other important general factors for individual differences in LTM include overall prior knowledge (knowledge of the current topic as well as knowledge about strategies and potential mediators) and overall self-efficacy (Hertzog & Dunlosky, 2004; Hertzog et al., 2007).

Relying on Nelson and Narens' (1990) influential framework should allow for a comprehensive and systematic investigation of the many different facets of individual differences in LTM. This would include examining variation in not only basic mechanistic processes, but also strategic processes and the extent to which mechanistic and strategic processes are related and interact. As noted by Melton (1967), "what is necessary is that we frame our hypotheses about individual differences variables in terms of the process constructs of contemporary theories of learning and performance" (p. 239). By utilizing current theoretical frameworks we should be able to examine important questions regarding individual differences in LTM and push the field forward.

Future Directions

The present article has provided an updated and comprehensive review of individual differences in LTM abilities. At the same time, it is clear that this line of research is in its infancy and much work remains to be done. For example, although there is quite a bit of research examining the overall factor structure of LTM abilities, there is considerably less work examining individual differences in the various cognitive mechanisms that are thought to give rise to differences in mean performance. As suggested in the last section, future research is needed to continue examining variation in monitoring and control processes that operate at encoding and retrieval and examine variation in a number of different memory phenomena. Furthermore, a key need for future research is to distinguish between variation in basic memory processes (mechanistic differences) and variation in the strategic control over memory. This will likely not be an easy task. Future research must be mindful of what the overall question is that is being addressed by the study and how the question and results fit in the context of an overall theory.

It will also be important to examine possible neural correlates of memory. Some prior research suggests that individual differences in memory abilities are related to variation in neural functioning (Kirchhoff, 2009; Kirchhoff & Buckner, 2006; Miller, 2009). For example, there is a small positive correlation between memory performance and hippocampal volume (Van Petten, 2004). Likewise, recent research suggests that medial temporal lobe activity during rest predicts individual differences in memory performance (Tambini, Ketz, & Davachi, 2010; Wig et al., 2008). Although these results are encouraging, one critical problem with these studies is that they are severely underpowered with sample sizes typically of only around 20–30 participants. Thus, only very strong correlations are found, because only strong correlations will be considered statistically significant with such small samples. Furthermore, given very small sample sizes the confidence intervals around such correlations will be unusually large, and although the correlation is deemed statistically significant, we will have almost no idea of the actual magnitude of the relation. A key endeavor for future research is to better examine neural correlates of individual differences in LTM abilities, but these relations should only be examined with sufficiently large sample sizes that are much larger than what is typically found in the field.

Examining individual differences in everyday memory will also be an important area of future research. All of the studies discussed in the current review have relied on laboratory tasks (typically list learning). However, to demonstrate the external validity of these tasks and findings, it will be important to demonstrate that they are related to individual differences in everyday memories. For example, a number of questionnaires that specifically examine everyday memory failures have been developed (e.g., Smith, Della Sala, Logie, & Maylor, 2000; see Herrmann, 1982, 1984 for reviews) and been found to correlate with one another and with spousal ratings of memory failures (e.g., Herrmann, Sheets, Gruneberg, & Torres, 2005). However, inconclusive results are found when examining the relation between self-reported memory failures and laboratory memory tasks. Specifically, significant correlations between memory questionnaires and laboratory memory tasks have been found in some studies for some measures (e.g., Cavanaugh & Poon, 1989; Kliegel & Jäger, 2006; Mäntylä, 2003; Sunderland, Harris, & Baddeley, 1983), whereas a number of studies have found weak to nonexistent correlations between some memory questionnaires and laboratory memory tasks (e.g., Herrmann, 1982; Mäntylä, 2003; Rabbitt & Abson, 1990; Sunderland et al., 1983). Thus, although a number of memory questionnaires have been developed that demonstrate individual differences in self-reported memory failures, the extent to which these questionnaires are related to laboratory memory performance remains unresolved. Another way of examining everyday memory abilities is through diary studies in which participants record their memory failures (Crovitz & Daniel, 1984; Terry, 1988). Shlechter, Herrmann, and Toglia (1990; see also Marsh, Hicks, & Landau, 1998) found strong correlations between self-reported memory failures from a questionnaire and diary responses. More recently, Unsworth, McMillan, Brewer, and Spillers (2013) had participants perform a number of tasks in the laboratory and carry a diary around for a week logging their various memory and attention failures. Unsworth et al. found that the most common memory failures were interrelated and loaded on the same latent factor, and this factor was related to LTM ($r = -.81$), WM ($r = -.38$), and SAT scores ($r = -.44$). Thus, there is some evidence that LTM abilities measured in the laboratory predict individual differences in everyday memories. While these initial results are encouraging, it is clear that much more research is needed to firmly establish that variation in LTM abilities in and out of the laboratory are the same.

As noted throughout, a promising means of examining individual differences in LTM abilities will be to combine experimental and correlational approaches as advocated by Cronbach (1957) and others (Cohen, 1994; Kosslyn et al., 2002; Underwood, 1975). Indeed, Johnson (2005; see also Cox, Hemmer, Aue, & Criss, 2018) has commented that:

> If experimental approaches stay alert to commonalities across tasks (and are not satisfied with local theories of very specific tasks), and individual differences approaches stay alert to components that may be represented in their latent variables (and are not satisfied with global explanatory constructs like episodic memory and executive function), these approaches should converge on a cumulative and cohesive picture of cognitive function. (p. 530)

Thus, it will be critical for future research to not simply examine correlations between LTM tasks and some other variable (such as intelligence), but rather to manipulate different task conditions to get a better sense of what factors are important in driving individual differences in LTM abilities.

When examining individual differences via correlations a number of important requirements must be considered to meaningfully interpret the results (see Salthouse et al., 2006; Salthouse & Siedlecki, 2007; Yarkoni & Braver, 2010). As noted throughout, a relatively large sample size is needed to get precise estimates of the magnitude of the relation. Given that many individual differences correlations are around .20–.30 (Gignac & Szodorai, 2016), this suggests the need for large sample sizes to not only detect these relations, but also to ensure that the confidence intervals surrounding the correlation are relatively narrow. For example, a correlation of $r = .50$ between hippocampal activity at rest and memory ability will have a 95% confidence interval ranging from .07–.77 with an N of 20. With an N of 200, however, the 95%

confidence interval will range from .39–.60. Thus, it is critically important that the sample sizes are sufficiently large to ensure that the study is properly powered. In addition to overall sample size, sample range is also critical. It is important that there is a sufficient range of abilities to properly estimate relations. If the range is restricted, then the overall magnitude of the correlations can be attenuated. Future research should ensure that the samples are sufficiently large with a large range of abilities to properly examine individual differences in LTM (and other) abilities.

Another critical factor when assessing correlations is whether or not the measures of interest are reliable. The reliability of a measure places an upper limit on potential correlations because reliability provides an estimate of the amount of systematic variance that is available and can be correlated with other measures. When reliability is low, the resulting correlations will tend to be low as well, making interpretation of the relations difficult. Thus, it is critical for each measure examined to assess the reliabilities to ensure that any differences in relations are not attributable to poor psychometric properties for the measures. Fortunately, many LTM measures demonstrate adequate reliabilities. For example, in Underwood et al. (1978) the average reliability for the free-recall tasks was .66 and for the paired associates tasks the average reliability was .73 (see also Unsworth, 2010a; Unsworth & Brewer, 2009, 2010a). In more recent research we have found that LTM measures have reliabilities ranging from .73–.85 (Unsworth, Fukuda, et al., 2014). Thus, when using measures like proportion correct in many LTM tasks, the resulting reliability estimates tend to be quite good. Additionally, as noted by Salthouse and colleagues (Salthouse et al., 2006; Salthouse & Siedlecki, 2007), when examining individual differences in LTM (and other abilities) we must be mindful of the distinction between the robustness of an effect and the reliability of a measure. Salthouse and Siedlecki (2007) note that:

> There is often confusion between what might be called robustness and reliability. A phenomenon can be robust if there are many replications of a significant finding, but it may not be reliable at the level of the individual. In fact, there can be an inverse relationship between robustness of a within-participant effect and measurement reliability because statistical significance is high when there is little variation across people in the magnitude of the effect (because this quantity is in the denominator of the ratio used to determine significance), but the lack of variance between people in the magnitude of the effect often is associated with low reliability. (p. 431)

Effects like proactive interference and the testing effect can sometimes be associated with low reliability because the overall within-subjects effect is small with little systematic variability between individuals. In such situations, correlations between these experimental effects and other individual differences measures can be low or nonexistent, not necessarily because there is no relation, but because the measure of interest is not reliable at the individual differences level (see Hedge, Powell, & Sumner, 2018 for a recent discussion). As noted throughout, many effects that rely on difference scores can have low reliabilities (Cronbach & Furby, 1970; Cohen & Cohen, 1983). It is not the case that difference scores are inherently unreliable, but rather that several factors can negatively influence the reliability of difference scores (Rogosa & Willett, 1983; Zumbo, 1999). The reliability of the difference score is determined by the reliability of the measures that go into the difference score as well as the correlation between those measures. When the reliability of the measures going into the difference score are low, the difference score reliability will also be low. Furthermore, as noted above, if the correlation between the two measures is high and most individuals demonstrate a similar difference score then there is little systematic variability that will be reliable. Future research must be mindful of the need to have reliable measures to meaningfully interpret any relations (or lack of relations) that are found.

Another important consideration for future research is whether single measures of a construct will be used or multiple measures. For example, finding a correlation between a single measure of intelligence and a single measure of LTM is informative, but this correlation does not provide much indication of the robustness of the relation and whether it will generalize to other LTM measures. When possible it is generally desirable to have multiple measures for each construct and to combine these measures into a single composite. In addition to relying on multiple measures per construct, it will also be important for studies to examine multiple constructs simultaneously to ensure that any relations found between LTM abilities and another construct are not due to a third variable. For example, given strong relations between WM and LTM, and WM and gF, a relation between LTM and gF could arise simply because of shared variance with WM. If WM is not measured it will be difficult to interpret any observed relation between LTM and gF in terms of direct effects. Future research should attempt to measure multiple indicators per construct and ensure that other meaningful constructs are measured to get a better sense of the possible multivariate relations.

Overall, it is clear that there are many open questions regarding individual differences in LTM abilities. As such, there are many avenues for future research. Critical for future research will be to ensure that studies have sufficient sample sizes (with sufficient range), measures are sufficiently reliable, multiple measures per construct of interest are examined, important relations are replicated, and the overall results are guided by and inform theories of LTM processes and individual differences therein.

Conclusions

In the current review, evidence has been presented suggesting that there are substantial and robust individual differences in LTM. These include individual differences in various lower order factors based on criterial tasks as well as individual differences in a more general higher-order LTM factor. These individual differences are associated with multiple different constructs including WM, intelligence, and attention control. Critically, LTM abilities represent partially unique abilities that are just as important as (and in some cases more important than) individual differences in WM, thus supporting a distinction between WM and LTM. Combined experimental and correlational approaches are needed to better understand individual differences in LTM and individual differences in LTM should be used to better test and revise theories of LTM processes. In writing this review, the most important thing I have learned is that we have only scratched the surface in terms of understanding individual differences in LTM.

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Appendix

Organizational Structure of the Review

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