DISSERTATION

PROCESS ESTIMATES OF RECOLLECTION AND FAMILIARITY IN WORKING MEMORY AND EPISODIC MEMORY

Submitted by

Vanessa Maria Loaiza-Kois

Department of Psychology

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Spring 2012

Doctoral Committee:

Advisor: Matthew G. Rhodes

Anne M. Cleary
Kurt Kraiger
Manfred Diehl

ABSTRACT

PROCESS ESTIMATES OF RECOLLECTION AND FAMILIARITY IN WORKING MEMORY AND EPISODIC MEMORY

Working memory is consistently shown to be related to episodic memory, but the underlying processes that contribute to this relationship are poorly understood. The following dissertation outlines a study which investigated the relationship between working memory and episodic memory, with particular regard to the contribution of familiarity and recollection processes to both constructs. Updating measures were also included to examine the potential mediating effects of updating on the relationship between working memory and episodic memory. Measurement models of both task performance and process estimates indicated a three-factor solution, with separate working memory, updating, and episodic memory factors. Such findings suggest that working memory, updating, and episodic memory are related but distinguishable constructs at the latent level of both task and process estimate.

DEDICATION

For DMc.

TABLE OF CONTENTS

CHAPTER I

Introduction

Among the most fundamental questions in both theoretical and applied cognitive psychology is how currently active information in consciousness is later retrievable. The question has traditionally been studied under the rubric of working memory and episodic memory. Using both experimental and individual differences methods, much research has investigated the processes that lead currently active information to become durable, long-term memories. The following dissertation examined measures of working memory, updating, and episodic memory using factor analysis in order to identify (1) the processes underlying working memory and episodic memory performance, (2) the extent to which these processes are related to one another, and (3) a potential mediator between these constructs.

Working Memory

Working memory is typically considered the immediate and limited mental workspace that supports other complex, higher order cognition such as fluid intelligence (Ackerman, Beier, & Boyle, 2005; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004), reading comprehension (Daneman & Carpenter, 1980; Turner & Engle, 1989), and episodic memory (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Park et al., 1996; Unsworth & Brewer, 2009). A number of models have been proposed to explain the nature of working memory and its relationship to other higher order cognition. In the original multimodal model, working memory was considered a limited capacity system responsible for maintaining information briefly while engaging in other processing activities (Baddeley, 1986). Thus, working memory capacity, or the efficiency of the system to maintain information, was attributable to three components: two passive storage buffers (i.e., the phonological loop and the visual-spatial sketchpad) and the central executive. The storage buffers maintained information by means of rehearsal (i.e., the phonological loop) and visual caches (i.e., the visual-spatial sketchpad). The central executive was responsible for allocating attentional resources to maintaining information in the storage buffers while also engaging in other processing activities (Baddeley, 1986).

A number of tasks have been developed to test working memory capacity, or the efficiency of the central executive, such as complex span tasks. Complex span tasks typically present to-be-remembered stimuli (e.g., digits or letters), interspersed between a distracting processing component, such as solving operations (Turner & Engle, 1989) or reading sentences (Daneman & Carpenter, 1980). A complex span trial repeats this processing component-stimulus sequence several times within a trial before a recall cue. Complex span tasks can be contrasted with simple span tasks, which typically only present a series of to-be-remembered letters or digits without a processing task before a recall cue. Simple span tasks are presumed to test the functioning of the slave systems without the central executive (but see Unsworth & Engle, 2006). Thus, complex span tasks are typically used as measures of working memory capacity and have been shown to be related to complex higher order cognition, such as episodic memory (McCabe et al., 2010; Park et al., 1996; Unsworth & Brewer, 2009). These relationships were originally interpreted within the context of the multimodal model. However, since the original multimodal model, a number of other frameworks of working memory have been proposed that focus more on working memory as the capacity to execute control over task-relevant information (Engle & Kane, 2004) and to switch information between varying levels of activation (Cowan, 1999; Oberauer, 2002; Unsworth & Engle, 2006).

Engle and colleagues (Engle, 2002; Engle & Kane, 2004) have proposed that individual differences in working memory capacity are less attributable to actual storage and more attributable to a general ability to control attention to task-relevant information in the face of interference. Thus, tasks that require increased controlled attention should more accurately assess working memory capacity, which also increases their predictive utility for other measures of higher order cognition (Engle & Kane, 2004). Conversely, performance on tasks that do not require the same degree of controlled attention to be completed effectively (i.e., tasks that can be completed using automatic processes) should not differ based on working memory capacity. For example, Kane, Bleckley, Conway, and Engle (2001) presented low- and high-span working memory individuals with prosaccade and antisaccade tasks. During the prosaccade task, individuals were instructed to respond to a stimulus that appeared in the same location as an initial visual cue. During the antisaccade task, individuals were instructed to respond to a stimulus that appeared in the opposite location of the cue. Although both span groups performed equivalently in the prosaccade condition, differences between the span groups emerged for performance on the antisaccade task, such that high-span individuals were faster to respond to the stimulus than low-span individuals (Kane et al., 2001). These data suggest that working memory capacity is unrelated to tasks that can be achieved by simple prepotent or automatic processes.

An implication of the executive attention framework is that factors like automaticity can influence performance on a task assessing working memory capacity, thereby diminishing its construct validity (Kane et al., 2001), as well as its predictive validity (Blalock & McCabe, 2011; McCabe, 2010). For example, Blalock and McCabe (2011) showed that reducing the degree of controlled processing that is necessary for optimal performance on a complex span task reduces the correlation between working memory capacity and fluid intelligence. Specifically, Blalock and McCabe (2011) had participants complete three blocks of a complex span task with pauses in-between trials (easy condition). Other participants completed three blocks of a standard complex span task without pauses between trials (difficult condition). Completing the span task under easy conditions resulted in a comparatively lower correlation with fluid intelligence by the third block relative to the difficult version of the span task (Blalock & McCabe, 2011). This suggests that conditions that modify the degree of controlled attention necessary for completing a complex span task will also modify the task's relationship with higher order cognition, such as fluid intelligence. Thus, any processes supporting performance that are unrelated to controlling attention (i.e., automatic processes) are unimportant to the relationship between working memory and higher order cognition.

Embedded processes models (Cowan, 1999; Oberauer, 2002; Unsworth & Engle, 2006), although different from one another in many respects, share the view that working memory is best conceptualized as a subset of information in variable states of activation within a larger context of long-term memory. These models emphasize the ability to flexibly select relevant information from a subset of activated representations in long-term memory into a limited-capacity focus of attention for processing. This selection mechanism is sometimes termed focus switching (Unsworth & Engle, 2008; Verhaeghen & Hoyer, 2007), refreshing (Higgins & Johnson, 2009; Johnson, Reeder, Raye, & Mitchell, 2002), or updating (Schmiedek, Hildenbrandt, Lövdén, Wilhelm, & Lindenberger, 2009a). For purposes of clarity, the term "updating" will be used to refer to this mechanism of activating new or once-active information in the focus of attention (but see Verhaeghen & Hoyer, 2007 regarding differences between the terms). Furthermore, this updating mechanism has been differentiated from other mechanisms of maintenance, such as rehearsal (Camos, Lagner, & Barrouillet, 2009; Camos, Oberauer, & Lagner, 2010; Hudjetz & Oberauer, 2007).[1]

Some proponents of embedded processes models have also contended that binding of item-specific information to a source context occurs in working memory (Naveh-Benjamin, Cowan, Kilb, & Chen, 2007; Oberauer, 2005; Oberauer, Süβ, Wilhelm, & Sander, 2007; Szmalec, Verbruggen, Vandierendock, & Kemps, 2010), which is purported to be related to updating of information (Bao, Li, Zhang, 2007; Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Oberauer, 2005; Oberauer & Vockenberg, 2009). For example, Oberauer (2005) showed that a latent factor of common variability from tasks requiring updating in working memory was significantly correlated with a latent factor of variability in performance on a task that required binding item information to a source context. Additionally, binding information to a source context may be susceptible to increased cognitive load (Oberauer & Vockenberg, 2009), as well as proactive interference from previously learned source contexts (Szmalec et al., 2010). For example, Oberauer and Vockenberg (2009) showed that both verbal and spatial item information originally presented in a specific location was accessed more quickly if that information was presented in the same location rather than another location. This facilitation effect was reduced with increased cognitive load and dissipated with increased lag

---

[1] Updating is often considered an executive function all its own, among others (Miyake et al., 2000; Oberauer et al., 2007). Although the status of working memory as it relates to executive functioning is contentious (McCabe et al., 2010), there is some consensus that working memory and updating are highly related constructs (Miyake et al., 2000; Oberauer, Süβ, Wilhelm, & Wittmann, 2008), if not isomorphic with each other (Schmiedek et al., 2009a). Oberauer and colleagues (Oberauer et al., 2007, 2008) suggest that all other executive functions should be unrelated to working memory capacity except for updating. Thus, variability in tasks that purportedly tax working memory capacity may be little more than the more basic process of updating information.

between presentations of different items in that location (Oberauer & Vockenberg, 2009). According to Oberauer and colleagues, the ability to bind information flexibly within working memory is the source of the relationship between working memory and higher order cognition (Oberauer et al., 2007). Thus, updating information appears to be important for bringing information into consciousness from less active states and may be related to processes that bind representations to specific source contexts in working memory.

Despite differences between the executive attention framework and embedded processes models, there are two areas of important theoretical overlap. First, both frameworks address the influence of automatic processing on working memory performance. For example, Schmiedek, Li, and Lindenberger (2009b) have shown that familiarity, or a feeling of recognition in the absence of contextual detail, may systematically influence performance on tests of working memory capacity, such as the *n*-back task. This task requires participants to indicate whether a currently presented stimulus matches the stimulus presented *n* trials back (e.g., “yes” would be the correct answer to B-A-B in a 2-back, but “no” would be the correct answer to a lure trial A-B-B). Schmiedek et al. (2009b) reported that older adults were faster than younger adults at identifying targets in the *n*-back paradigm, but exhibited increased response times and more false alarms to lures. This suggests that older adults’ performance on the task was largely driven by familiarity in the absence of bound source-item information (Schmiedek et al., 2009b; cf. Jacoby, 1999). From an embedded processes model perspective, these data reflect a failure to appropriately bind information in working memory but is also consistent with predictions of Engle and colleagues’ executive attention model. That is, tasks that can be completed without taxing controlled attention should not differentiate on the basis of working memory capacity (Engle & Kane, 2004). Therefore, to the extent that familiarity can be considered a type of automatic response (i.e., a process that does not require controlled attention; cf. Jacoby, 1991), older adults' correct performance was comparable to that of younger adults because responses were based on relatively intact familiarity (Schmiedek et al., 2009b). Thus, both frameworks concede an influence of automatic processing, such as familiarity, that may systematically influence working memory performance in conditions that may depend on familiarity. The shared implication between the two working memory frameworks is that tasks purported to tax working memory are not pure measures of controlled processing, but in some cases may reflect more automatic processes.

A second area of overlap between the frameworks is the degree to which controlled processing is necessary to the functioning of working memory. Indeed, Oberauer has conceded that the executive attention framework (e.g., Engle & Kane, 2004) may be compatible with his embedded processes model insofar as controlled attention is necessary for binding information in working memory (Oberauer et al., 2008). Consistent with this, Naveh-Benjamin et al. (2007) have shown that dividing attention during encoding hinders binding of information in working memory. Likewise, according to the executive attention framework, controlled attention minimizes the influence of task-irrelevant information on performance. This task-irrelevant information may be considered similar to the influence of the familiarity of related lures that must be overcome by binding information to specific source contexts (Schmiedek et al., 2009b; Szmalec et al., 2010).

Thus, Engle and colleagues have considered controlled attention as necessary for keeping task-relevant information active in the face of interference, while Oberauer and colleagues have considered controlled attention as necessary for binding representations to a source context. Although the consequences of controlled attention serve different goals between the respective frameworks, it does not appear that the executive attention and embedded processes models of working memory are mutually exclusive. Rather, a synthesis of the data supporting the respective frameworks suggests that controlled attention is necessary for working memory, potentially serving to bind representations to source contexts by means of updating. When information is not sufficiently bound, more automatic processes (e.g., familiarity) may cause interference and influence performance.

Dual Process Models of Episodic Memory

Research in episodic memory parallels research on the influence of controlled and automatic processes in working memory. Episodic memory is typically considered information that can be explicitly retrieved once it is no longer maintained in working memory. Episodic memory tasks generally involve tests of recognition, recall, and cued recall after a filled retention interval of at least 30 seconds to ensure that information is no longer maintained in working memory. All of these episodic memory tests operate on the assumption that information is no longer maintained actively in working memory and must be retrieved from a store of longer duration.

A contentious area in recognition memory, in particular, concerns the nature of underlying processes supporting performance. Namely, does recognition memory performance reflect a single dimension of memory strength or two discrete processes of familiarity and recollection? Single process models, such as the unequal-variance signal-detection model (Wixted, 2007), typically posit that a single process of memory strength underlies recognition memory performance. Thus, a decision of whether an item was previously studied is determined by the overall strength of the memory trace. Dual process models, in contrast, posit that a recollection process, in addition to a strength-based familiarity process, supports recognition memory performance (see Yonelinas, 2002, for a review). Recollection is a slower, more controlled process that reflects retrieval of specific details of an event, whereas familiarity is considered a faster and more automatic experience of recognition in the absence of contextual detail. Experimental evidence in support of dual process models is evident in dissociations between processes. For example, dividing attention influences recollection but not familiarity (Jacoby, 1999; Jacoby, Toth, & Yonelinas, 1993). The present study tested single-process and dual-process perspectives with the predicted outcome favoring two processes that support episodic memory performance.

Parallel to the aforementioned working memory literature, the importance of controlled and automatic processes for episodic memory performance has been extensively investigated. Some researchers have noted that performance on episodic memory tests should not be considered as pure measures of either recollection or familiarity (Jacoby, 1991, 1998; McCabe, Roediger, & Karpicke, 2011), and thus more precise estimates of processes are necessary to understand recognition memory performance. In order to respond to this limitation, Jacoby (1991) developed the process dissociation procedure (PDP) on the premise that recollection and familiarity correspond to controlled and automatic processes, respectively, which independently contribute to recognition performance (Jacoby 1991, 1998). Using PDP, Jacoby (1991, 1998) derived estimates of recollection and familiarity under the assumption that typical tasks with instructions to respond "old" to anything that was previously studied, regardless of the original context, can be completed on the basis of recollection (R) and familiarity (F) in the absence of recollection (1 – R). Performance on such an "inclusion" test can be captured in the following equation:

$$\text{Inclusion} = R + F(1 - R)$$

However, tasks that require participants to respond based on whether information was studied in a certain context (e.g., reading words vs. solving anagrams) require recollection. That is, participants are asked to distinguish item-level information (e.g., words) from the original study context (e.g., reading or solving). Such distinctions require that contextual information be retrieved. Thus, any intrusions from another context (e.g., responding "old" to a word that was read instead of solved) can be classified as familiarity-based responses because participants did not successfully recollect that the information was presented in another context (e.g., read) than the one specified for correct retrieval decisions (e.g., solved). Errors in such an "exclusion" task reflect familiarity in the absence of recollection and are captured in the following equation:

$$\text{Exclusion} = F(1 - R)$$

Given the differential contributions of recollection and familiarity processes to recognition memory performance, it is possible to derive independent estimates of these processes using inclusion and exclusion performance. Recollection can be estimated by subtracting errors on an exclusion task (i.e., errors that reflect familiarity) from correct performance on an inclusion task:

$$\text{Recollection} = \text{Inclusion} - \text{Exclusion}$$

Familiarity would be calculated as false alarms on the exclusion task divided by the inverse of the recollection estimate:

$$\text{Familiarity} = \text{Exclusion}/(1 - R)$$

The assumption of the PDP framework is that process estimates are direct indices of recollection and familiarity, whereas task performance always involves unquantifiable contributions of recollection and familiarity. From this perspective, it is important to use process estimates instead of task performance to understand the contribution of recollection and familiarity to episodic memory performance. For example, a number of factors have been shown to differentially impact estimates of recollection and familiarity (see Yonelinas, 2002, for a review), such as dividing attention during encoding (Jacoby, 1993, 1999). This supports the prediction that both processes contribute independently to recognition memory performance. Additional evidence indicates that these processes are not limited to recognition memory performance, but are also evident in other tests of episodic memory, such as free recall (McCabe et al., 2011; Unsworth & Brewer, 2009) and cued recall (Jacoby, Wahlheim, Rhodes, Daniels, & Rogers, 2010; Unsworth & Brewer, 2009). Thus, even tasks that are considered purer measures of recollection-based responding, such as recall, may reflect independent contributions of recollection and familiarity.

In sum, the arguments of the PDP framework parallel those of the executive attention and embedded processes models of working memory concerning the influence of controlled processing and automaticity on task performance. Namely, recollection is a more controlled process that requires retrieval of an original source context, but memory performance may still be influenced by more automatic processes, such as familiarity. Thus, it is important to directly estimate the influence of these two underlying processes in order to understand their contribution to task performance. As suggested in the following section, such process estimates may also further elucidate the relationship between working memory and episodic memory.

The Relation between Working Memory and Episodic Memory

There is a consistently established relationship between working memory capacity and episodic memory performance from both individual differences (McCabe et al. 2010; Park et al., 1996; Unsworth & Brewer, 2009) and experimental (Johnson et al., 2002; Loaiza & McCabe, 2012; Loaiza, McCabe, Youngblood, Rose, Myerson, 2011; McCabe, 2008; Rose, Myerson, Roediger, & Hale, 2010; Sederberg, Miller, Howard, & Kahana, 2010) perspectives. First, at a latent variable level, variability common to measures of working memory significantly predicts variability common to episodic memory performance (McCabe et al., 2010; Park et al., 1996; Unsworth & Brewer, 2009). For example, McCabe et al. (2010) reported that an executive attention latent construct of variability from working memory and executive functioning measures significantly accounted for age-related variability in episodic memory performance. However, as noted previously, this relationship can be reduced if conditions of a complex span task allow for the influence of automaticity on task performance (Blalock & McCabe, 2011). Likewise, the influence of automaticity on episodic memory task performance may also change the relationship between working memory and episodic memory. Specifically, Unsworth and Brewer (2009) showed that variability common to several complex span tasks was related to a recollection construct representing variability across item-based and source-recognition episodic memory tasks, but that the working memory construct was not related to residual variability from item-specific episodic memory measures representing familiarity. Thus, the contribution of automatic processes (e.g., familiarity) to performance on working memory and episodic memory measures alike may change the magnitude of the relationship between the two constructs.

Although the constructs are typically highly related, working memory and episodic memory tasks have not been shown to load on a single memory factor without significantly impairing model fit (McCabe et al., 2010; Park et al., 1996; Unsworth & Brewer, 2009). For example, Park et al. (1996) reported that a latent variable representing working memory better served as a predictor of age-related changes in episodic memory rather than as an indicator of general episodic memory performance. Similarly, Unsworth, Brewer, and Spillers (2009) showed that while complex span tasks share much variability with episodic memory tasks, a residual construct of variability purportedly representing active maintenance in working memory (i.e., variability unassociated with episodic memory) predicted fluid intelligence to a similar degree as episodic memory. Thus, it appears that working memory and episodic memory are highly related but still distinguishable constructs.

Experimental evidence also suggests that working memory and episodic memory are distinguishable but strongly related constructs. However, experimental paradigms typically focus on the mechanisms supporting working memory performance that may change later retrieval of that information from episodic memory. Much recent research has emphasized the importance of updating in working memory, distinguishable from articulatory rehearsal, as a mechanism that supports long-term retrieval (Johnson et al., 2002; Loaiza & McCabe, 2012; McCabe, 2008). For example, Johnson et al. (2002) showed that later recognition memory was superior for items that originally had to be immediately updated at a cue compared with items that were simply immediately re-presented. McCabe (2008) also showed a strong relationship between the number of times an item from a working memory trial was updated and subsequent episodic memory performance. Specifically, McCabe (2008) presented participants with four words to remember in a simple span task and a complex span task. Because the four words in a simple span task could be quickly recalled from the focus of attention (Cowan, 1999), those words should not have required any updating to keep them active. Complex span tasks, in contrast, require information to be switched between the focus of attention and a less active state of background maintenance because the distracting processing task requires consistent updating for optimal performance. Furthermore, the first word presented in a complex span trial will have more opportunities to be updated than the last item of a trial. McCabe (2008) reported that words that were studied earlier during a complex span task trial were more likely to be retrieved during delayed recall than later-presented words within the same trial. In contrast, delayed recall did not vary based on serial position for the simple span task, suggesting that words from simple span tasks were never updated, regardless of their serial position. Thus, words that had more opportunities to be updated were more likely to be retrieved than words that were rarely or never updated in working memory.

An implication of these data is that the temporal context (i.e., serial position) of an item is intrinsically tied to its opportunity to be updated in working memory (Loaiza & McCabe, 2012). Therefore, the original temporal context in which information was studied may strongly predict episodic memory performance. Consistent with this, Sederberg et al. (2010) showed that episodic memory (i.e., free recall) performance was higher when retrieval was guided by associations made between items and their original respective temporal contexts. Thus, binding item information to a specific source context (in this case, temporal context within a trial) occurs in working memory and is particularly important for later retrieval of that information from episodic memory. Additionally, the ability to update information in working memory appears to be related to the process of binding information to a source context, such that the associated temporal context of an item is more salient for retrieval from episodic memory if the bound information had relatively more opportunities to be updated (Loaiza & McCabe, 2012; McCabe, 2008).

Another area in which experimental data have converged with those of individual differences studies regards the extent to which episodic memory contributes to working memory. Indeed, according to the embedded processes models, working memory is an activated subset of information within episodic memory, and thus episodic memory may influence working memory performance. For example, recent research has investigated the influence of retrieval from secondary memory (i.e., episodic memory) during complex span tasks (Unsworth & Engle, 2006; Loaiza et al., 2011; Rose et al., 2010). There is some indication that factors that affect episodic memory performance (e.g., the level of processing during encoding) also affect retrieval from working memory (Loaiza et al., 2011; Rose et al., 2010). Furthermore, Zhang and Verhaeghen (2009) have shown that information that lacks established semantic representations, such as Chinese characters for English-speaking individuals, is more difficult to update and access in working memory than information with established semantic representations, such as English words. These data suggest that established episodic memory representations facilitate working memory performance. However, the variability of the representative tasks rarely, if ever, load on the same construct. Thus, it is possible that the key difference between working memory and episodic memory tasks is the requirement of actively maintaining information in working memory for ongoing processing (Unsworth et al., 2009), which is purportedly captured by the mechanism of updating (Bunting et al., 2006). Although this mechanism may distinguish working memory from episodic memory, updating in working memory may later support episodic memory performance.

Current Study

In sum, although there is an established relationship between working memory and episodic memory, all prior work has drawn conclusions based on task performance (i.e., number of items correctly remembered), which cannot be considered a pure measure of controlled attention and retrieval. Factors such as automaticity may influence performance and suppress the relation between working memory and episodic memory. Jacoby’s PDP framework allows these processes to be estimated in episodic memory, but working memory researchers have only attempted to minimize the influence of automaticity by manipulating the experimental conditions of the tasks (e.g., Blalock & McCabe, 2011; McCabe, 2010). No one has yet considered the same process dissociation for working memory tasks.

Recent data from our lab indicate that the PDP can be implemented in working memory tasks by requiring participants to engage in inclusion- or exclusion-based responding at immediate retrieval. These data showed that recollection was affected by the presentation rate of information, but familiarity was not, suggesting that these two processes can be dissociated in working memory as in episodic memory (McCabe & Loaiza, 2010). The goal of this dissertation was to systematically estimate controlled and automatic processes in working memory and episodic memory using the PDP. The use of the PDP was meant to account for variability due to automatic processing that may suppress the relationship between both constructs. Furthermore, the study also included measures of updating in order to determine its role as a mechanism in working memory that may subserve conscious recollection in episodic memory. Conversely, updating may be unrelated to the relationship between familiarity in working memory and episodic memory, suggesting that not all processes that support working memory performance are ubiquitously important for processes in episodic memory. This would expand upon previous findings that working memory is related to conscious recollection and not familiarity (Oberauer, 2005; Unsworth & Brewer, 2009), and also demonstrate that working memory can be decomposed into those processes. Moreover, recollection and familiarity processes in working memory may be differentially related to those respective processes in episodic memory.

To this end, the current factor analysis study included multiple tasks representing the constructs of working memory, updating, and episodic memory. The working memory and episodic memory tasks included both inclusion and exclusion instructions in order to attain process estimates of recollection and familiarity in each respective task. I predicted that an initial measurement model, based on task performance, would indicate three distinct latent factors representing working memory, updating, and episodic memory that are highly related to each other (see Figure 1, Model A). Alternative measurement models might indicate one latent factor of working memory, comprising working memory and updating tasks (see Figure 1, Model B), supporting the hypothesis that working memory and updating are isomorphic (Schmiedek et al., 2009a). Still another potential model was that one latent factor would comprise variability in all of the tasks (see Figure 1, Model C), supporting the hypothesis that working memory and episodic memory are not distinguishable (Mogle, Lovett, Stawski, & Sliwinski, 2008). For reasons mentioned previously, I anticipated that these other models would not fit the data as well, especially when considering the issue of task impurity. Specifically, there may be multiple processes that influence performance on working memory and episodic memory tasks, which would contaminate the extent to which the factors can be considered redundant with each other.

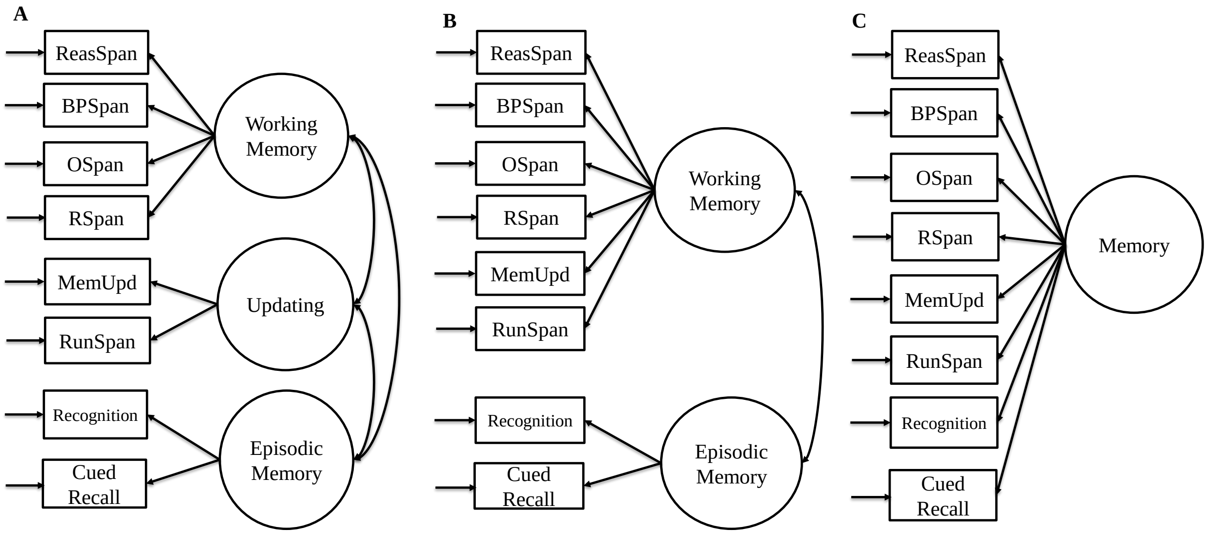

Figure 1. Possible measurement models of performance on the eight manifest variables.

Secondly, when decomposing working memory and episodic memory performance into recollection and familiarity estimates, I predicted that recollection and familiarity estimates within each task would load on separable factors of working memory recollection, working memory familiarity, episodic memory recollection, and episodic memory familiarity. The recollection and familiarity factors should be unrelated to each other, confirming the assumption of independent processes (Jacoby, 1991, 1998), but the recollection and familiarity factors of working memory should be highly related to their respective factors in episodic memory. Furthermore, updating was expected to be highly related to both working memory and episodic memory recollection factors, but not the familiarity factors (see Figure 2, Model A). Alternative models that predict fewer factors are also plausible. Specifically, updating may be considered redundant with working memory recollection (see Figure 2, Model B), recollection and familiarity estimates between working memory and episodic memory may be redundant with each other (see Figure 2, Model C), or there may simply be two constructs of recollection and familiarity that account for all of the variability of these tasks (see Figure 2, Model D). If working memory and episodic memory are separable constructs, I do not anticipate that the latter two models would obtain. However, the four-factor model (Figure 2, Model B) may be plausible given the finding that working memory and updating tasks load on the same factor (Schmiedek et al., 2009a).

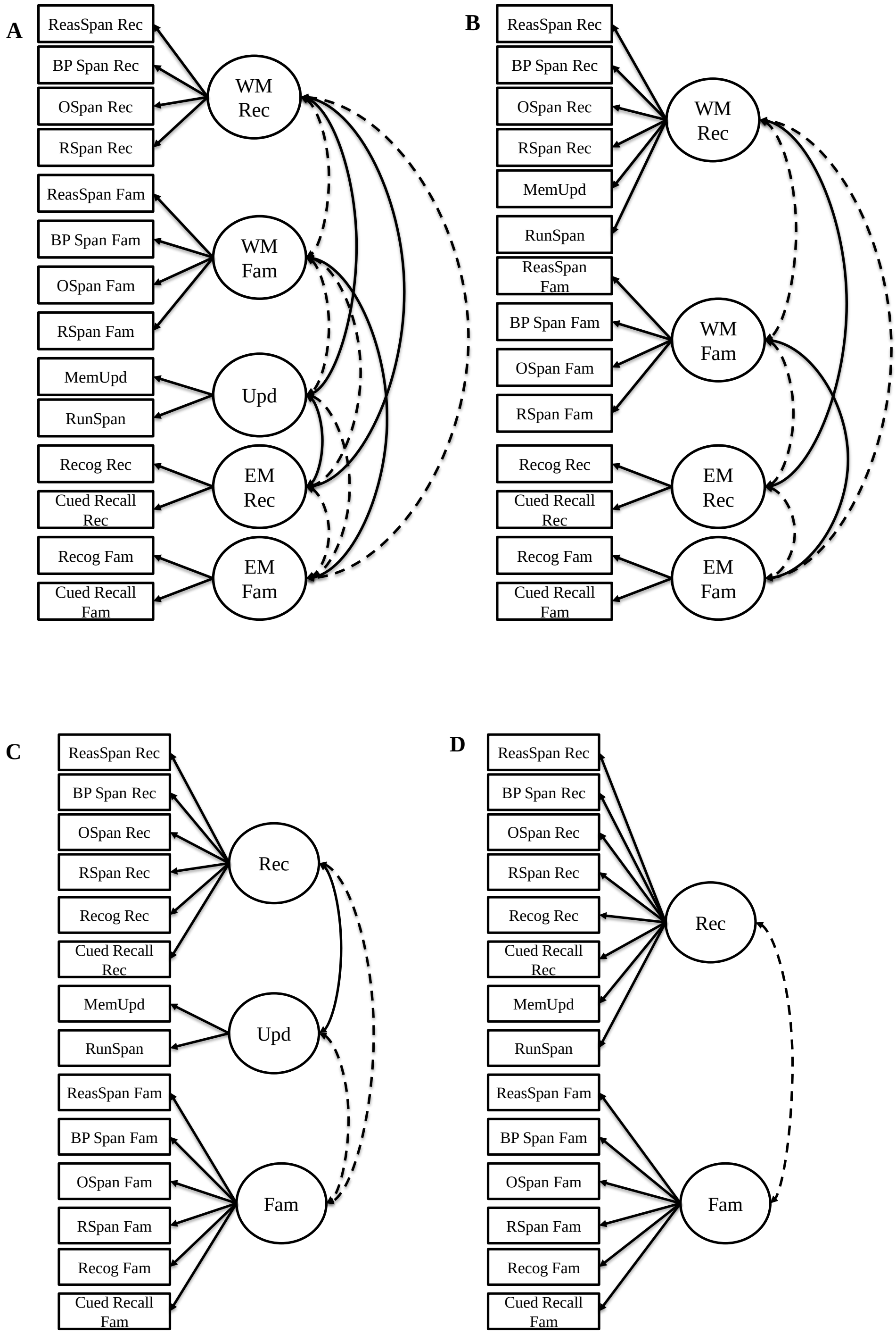

Figure 2. Possible measurement models with performance from working memory and episodic memory tests decomposed into recollection and familiarity estimates.

Finally, if the measurement model shown in Figure 2, Model A, is the best model fit of the process estimate variability from the working memory and episodic memory tasks, then this will allow a test of the structural equation models shown in Figure 3. Model A should have a better fit than Model B, indicating that decomposing working memory and episodic memory performance into respective recollection and familiarity estimates should yield a superior fit than using latent factors derived from task performance for identifying the role of updating as a mediator between working memory and episodic memory.

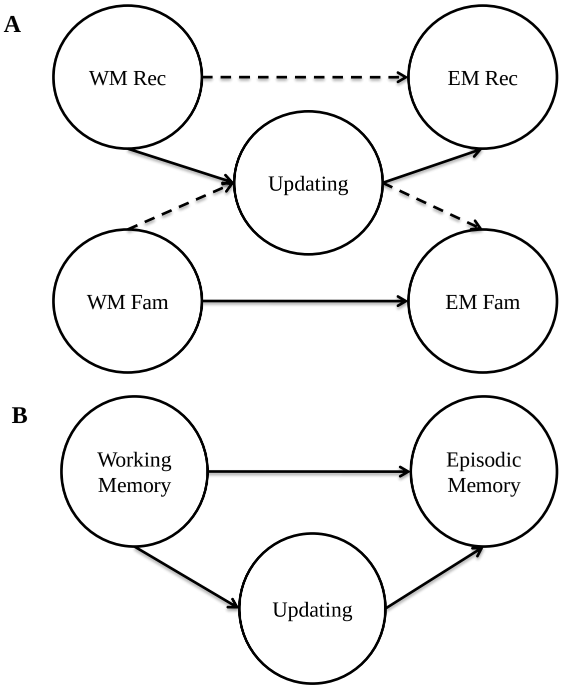

Figure 3. Structural equation models examining the relationship between working memory and episodic memory latent variables.

CHAPTER II

Method

Participants

Two hundred forty-six younger adults (155 female, age *M* = 18.74, *SD* = 1.21) were recruited from the CSU subject pool for this study. Each participant was tested in two sessions lasting approximately 1.5 hours each. Eight participants were dropped for failure to complete at least one (but never more than two) of the measures shown in Table 1 (see Data Analysis).

Materials and Procedure

Each participant completed the tasks in the following order: Reasoning Span, Brown-Peterson Span, Operation Span, Reading Span and a demographics questionnaire during session 1. During session 2, all participants completed the Memory Updating task, Running Memory Span, a cued recall task, and a recognition task.

The tasks included were intended to represent the constructs of working memory (Reasoning Span, Brown-Peterson Span, Operation Span, and Reading Span), updating (Memory Updating, Running Memory Span), and episodic memory (cued recall and recognition). For the four working memory tasks, the order of inclusion and exclusion blocks was counterbalanced, such that half of the participants completed the inclusion block first followed by the exclusion block for half of the tasks. The other half of the participants completed the tasks with the opposite presentation order of the inclusion and exclusion blocks. For example, half of the participants completed the inclusion block first in the Reasoning Span task, the exclusion block first in the Brown-Peterson Span task, the inclusion block first in the Operation Span task, and the exclusion block first in the Reading Span task. This presentation order of the blocks was switched for the other half of the participants.

Working Memory Tasks

Reasoning Span. In the Reasoning Span task, participants viewed and attempted to remember digits interspersed between solving reasoning problems. Participants initially completed a practice task in which they practiced 30 representative reasoning problems that later served as the processing component of the Reasoning Span task. The reasoning problems were adapted from the active problem types described in Saito, Jarrold, and Riby (2009). Each reasoning problem regarding a provided letter combination (e.g., “H does follow F – FH”) was read aloud, and participants indicated whether the sentence accurately described the provided letter combination (e.g., “true”). Half of the problems were true and half were false (e.g., “B doesn’t precede N – BN”).

Depending on the counterbalance, participants were given instructions for the inclusion or exclusion block after completing the reasoning practice phase. During the inclusion block, participants were instructed to complete the reasoning problems as they had done earlier during the practice phase. After completing the reasoning problem, the experimenter advanced the screen to a single-digit (0 through 9) that was presented for 1000 msec. This sequence repeated five times within a trial. At the end of each trial participants were required to recall the five presented digits in any order they wished. During the exclusion trials, participants similarly completed five reasoning problems, each of which was followed by a single-digit for 1000 msec. However, at the end of the exclusion trials, participants were instructed to recall the five digits that were *not* presented. Thus, if the participant saw the digits “0 4 7 1 9,” they would have reported “2 3 5 6 8” during the exclusion trials. The presented digits never followed a forward or backward numerical order (e.g., 1 never preceded or followed 2). There were 10 trials, presented in a random order, in each of the inclusion and exclusion blocks.

Brown-Peterson Span. The Brown-Peterson Span task was very similar to the Reasoning Span task, except that all five of the digits to remember were presented prior to solving the reasoning problems. Having already had sufficient practice with the reasoning problems, participants either began the inclusion or exclusion block depending on the counterbalance. Participants viewed five single-digits on the screen for 1000 msec each. Afterward, participants read aloud and responded to five reasoning problems. The inclusion block required participants to recall the five presented digits from the trial, whereas the exclusion block required participants to recall the five digits that were *not* presented during the trial. There were 10 randomly presented trials of each of the inclusion and exclusion blocks.

Operation Span. The Operation Span task used was adapted from the automated Operation Span task developed by Unsworth et al. (2005). The procedure was similar to the Reasoning Span task, except that participants read aloud and responded to multiplication problems before viewing letters to remember. The participants were also required to recognize the letters by clicking on them on the computer screen rather than recalling them aloud. Participants first completed 30 practice multiplication problems to become familiar with the multiplication problems that were used in the task. The multiplication problems were composed of single digits between 4 and 7, half of which had a provided response that was correct. The other half had included an incorrect response within one or two digits of the correct response (e.g., “7 x 4 = 26?”).

Depending on the counterbalance, the participant then received instructions for the inclusion or exclusion block. During both blocks, the participant read aloud a presented multiplication problem (e.g., “7 x 4 = 28?”), which they indicated was true or false. The experimenter then advanced the screen to a letter (F, H, J, L, N, P, Q, R, S, and Y) that was displayed for 1000 msec. After five multiplication problems and letters had been presented, all 10 possible letter choices appeared in a 2 x 5 grid-like display, with boxes to check next to each. During the inclusion block, participants were instructed to select the letters that were presented during the trial. During the exclusion block, participants were instructed to select the letters that were *not* presented during the trial. Ten trials of each block were randomly presented.

Reading Span. The Reading Span task was adapted from the automated Reading Span task developed by Engle and colleagues (cf. Unsworth & Brewer, 2009). Reading Span is very similar to Operation Span except that, prior to the presentation of each single digit, participants were required to read aloud a sentence and respond to its veracity (e.g., “In the summer people fish in the river”). Half of the sentences were correct and the other half were nonsensical (e.g., “In the summer people fish in the grass”). All of the sentences were equated for word length (*M* = 8.76, *SD* = 1.13) and number of syllables (*M* = 11.84, *SD* = 1.16). After reading aloud and responding to each sentence, participants viewed a single-digit (0 through 9) presented for 1000 msec. After five sentences and digits had been presented, all 10 possible digit choices appeared in a 2 x 5 grid-like display, with boxes to check next to each digit. During the inclusion block, participants were instructed to select the five digits that were presented during the trial. During the exclusion block, participants were instructed to select the five digits that were *not* presented during the trial. Ten trials of each block were randomly presented. Digits were chosen as to-be-remembered stimuli for this task instead of letters to ensure that any potential difference in factor loadings between recognition working memory tasks and recall working memory tasks were not due to a difference in the type of information to remember.

Updating Tasks

Memory Updating. The Memory Updating task was adapted from Schmiedek et al. (2009a). Participants were presented with two rows of frames, varying randomly between two to five frames per row. Participants completed a block of 16 total trials, with four trials for each load level. At the beginning of each trial, participants silently read a single-digit (0 through 9) that was presented in each frame of the top row for 2000 msec. The digits in the first row then disappeared before addition and subtraction operations (e.g., “+ 2”, “- 4”) were presented in the second row of frames. The operations appeared one at a time at a 2000 msec rate in a fixed random order. Participants were instructed to update the digits in the first row of frames according to the operations in the second row of frames (see Figure 4 for an example trial). Each frame updated twice and a given frame was never updated twice in a row (i.e., the frame to update switched with the presentation of each operation). The values of the frames always remained within the range of 0 to 9. Participants were instructed to enter the final values of each frame using the keyboard when they saw the red question marks appear above the frames.

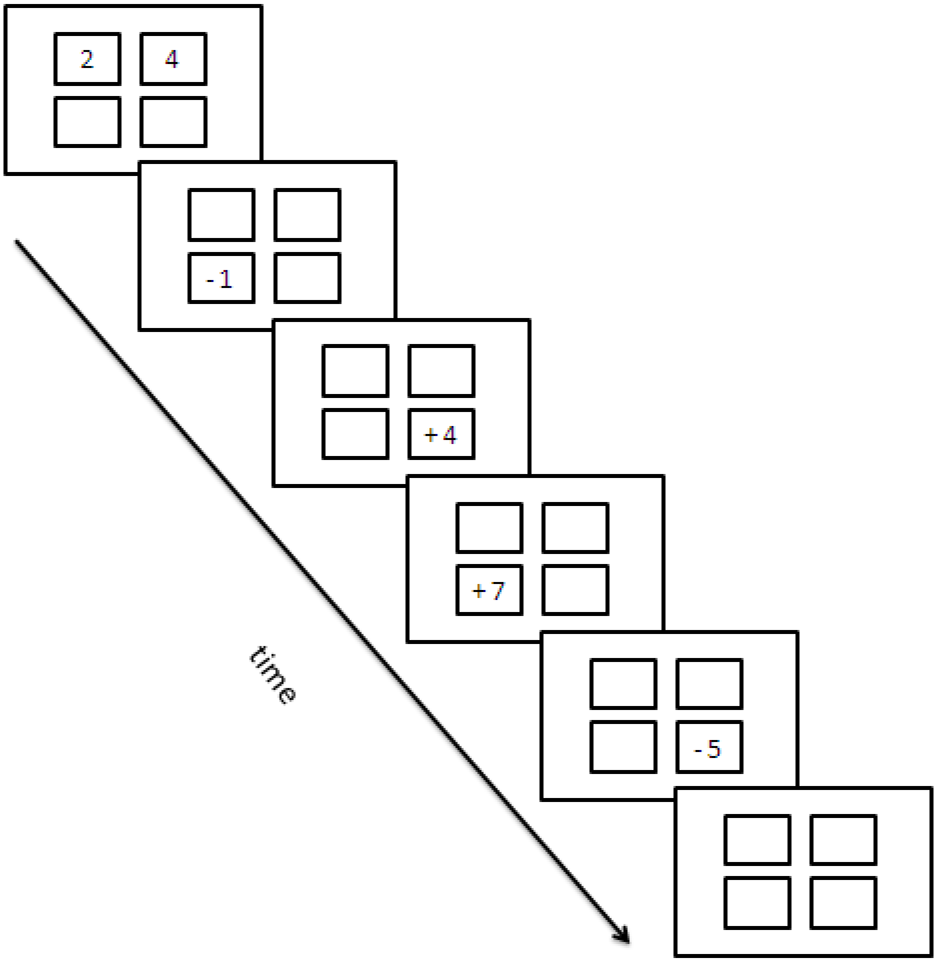

Figure 4. An example of a Memory Updating trial with two frames to update. Participants typed in their responses in the last blank frame.

Running Memory Span. The Running Memory Span task was adapted from Bunting et al. (2006) and required participants to report the last few letters of a trial of an unknown length. Before each trial began, participants were told how many letters at the end of each trial to report (between 3 and 7). Participants then studied a variable number of letters (B, F, H, J, L, M, Q, R, and Y) that appeared successively on the screen for 1000 msec each. At the end of each trial, participants attempted to recall the last *n* letters according to the instruction at the beginning of the trial (e.g., reporting the last 5 letters that were presented during the trial). The total number of letters presented within a trial varied *n* + 0, 1, 2, and 3 (with one total length for each report length). Thus, in some instances, the total number of letters presented was the number that participants had to recall (i.e., *n* + 0). There were 20 trials within 4 total blocks, with one trial of each report length (3-7) randomly presented within that block.

Episodic Memory Tasks

Cued Recall Task. The cued recall task was adapted from Jacoby et al. (2010) and was separated into three phases. During the initial, familiarization phase, participants were instructed to read aloud 48 related word pairs (e.g., apple - core), each randomly presented twice for 2000 msec. There were four buffer word pairs at the beginning and end of the phase to reduce primacy and recency effects. During the second, study phase, participants were instructed to read aloud 72 word pairs presented in a random order for 2000 msec each. They were told that their memory for these word pairs would be tested later in the experiment. Twenty-four of the word pairs in the second phase were congruent with the word pairs that had been presented during the first phase of the experiment (e.g., apple - core). Another 24 of the word pairs in the second phase were incongruent with the word pairs that had been presented during the first phase of the experiment, such that a new target was paired with the cue (e.g., apple - worm). The remaining 24 words of the second phase were new word pairs. There also were four buffer word pairs at both the beginning and end of the study list to account for primacy and recency effects, respectively. During the final, test phase of the task participants viewed the word pairs one at a time on the screen with some letters from the target word missing (e.g., “apple - _or_). They were instructed to recall the target that was paired with the cue during the second phase of the experiment and not the first phase. The test phase consisted of 72 word pair stems: 24 congruent word pairs (i.e., same target between the first and second phases; inclusion), 24 incongruent word pairs (i.e., different target between the first and second phases; exclusion), and 24 neutral word pairs that were only presented during the second study phase. The word pairs were counterbalanced across each of these conditions.

Recognition Task. The recognition task was adapted from Jacoby (1991) and was separated into three phases, similar to the procedure for the recognition task. In the first, familiarization phase, participants were instructed to read aloud 48 randomly presented concrete, five-letter nouns. Each word was presented once within two consecutive blocks for 3000 msec. There were four buffer words at the beginning and end of the block to account for primacy and recency effects. During the second study phase, participants were instructed to solve 48 anagrams for words randomly presented by the program for 3000 msec each. They were told that their memory for these words would be tested later in the experiment. Participants were instructed that all of the anagrams could be solved by switching the first and last letter of the anagram (e.g., “rhaic” is “chair”). Half of the anagrams presented during the study phase were also presented during the initial familiarization phase and the other half were entirely new anagrams. There were also four buffer anagrams at both the beginning and end of the study list to account for primacy and recency effects, respectively. Finally, during the test phase, words were presented one at a time, and participants were instructed to respond “yes” only to words that were solved as anagrams during the study phase of the experiment. If they recognized a word that was studied during the first phase of the experiment that was not presented as an anagram to solve during the second phase, they were instructed to respond “no.” The test phase consisted of 72 words: 24 congruent words (presented during both the first and second phases), 24 incongruent words (words presented only in the first phase), and 24 neutral words (words presented during only the second phase). Thus, any words that were presented during both the first and second phases required a “yes” response (i.e., inclusion). Any words presented only during the first phase, and not solved as anagrams during the second phase, required a “no” response (i.e., exclusion). The words were counterbalanced across each of these conditions, and were equated for number of syllables (*M* = 1.43, range = 1-2) and Log HAL frequency (*M* = 9.33, range = 8.01-11.68).

Data Analysis

Due to experimenter error, eight participants’ data were missing from at least one (but never more than two) of the measures (see Table 1 for a list of all 16 measures). Little’s MCAR test suggested these values were missing completely at random, $\chi^2(101) = 117.94$, *ns*. These participants were excluded listwise from all analyses.

It should also be noted that, in some cases, participants’ process estimates were negative or undefined. Cases of negative recollection usually occurred when exclusion errors exceeded inclusion accuracy for a specific working memory or episodic memory measure, thereby resulting in negative recollection. Cases of undefined estimates usually occurred for estimating familiarity when participants’ recollection estimates were perfect (and thus dividing exclusion errors by the inverse of recollection would be to divide a value by zero, resulting in an undefined estimate). The eight instances of negative recollection estimates were set to zero (cf. Jacoby, 1998). The seven instances of undefined familiarity were also set to zero. An estimate of zero was considered most appropriate in these instances because those with similar performance (e.g., a person with *nearly* perfect inclusion accuracy and no exclusion errors) also had familiarity estimates of zero.

CHAPTER III

Results

The measures of interest are task performance (proportion of recalled and recognized stimuli) across all eight tasks and the process estimates derived from task performance on the working memory and episodic memory measures. Process estimates were calculated using the equations reported by Jacoby (1991) and described previously. The descriptive statistics (mean, standard deviation, reliability, skew, and kurtosis) for these measures can be found in Table 1 (task performance) and Table 2 (process estimates). It should be noted that all factor loadings presented in the models are standardized estimates.

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. ReasSpan INCL	-															
2. ReasSpan EXCL	**-.57**	-														
3. BPSpan INCL	**.54**	**-.56**	-													
4. BPSpan EXCL	**-.59**	**.71**	**-.59**	-												
5. OSpan INCL	**.41**	**-.46**	**.36**	**-.45**	-											
6. OSpan EXCL	**-.38**	**.51**	**-.37**	**.51**	**-.62**	-										
7. RSpan INCL	**.35**	**-.38**	**.35**	**-.36**	**.26**	**-.43**	-									
8. RSpan EXCL	**-.41**	**.48**	**-.44**	**.46**	**-.41**	**.46**	**-.59**	-								
9. Mem Upd	**.23**	**-.30**	**.26**	**-.30**	**.32**	**-.32**	**.22**	**-.28**	-							
10. Run Span	**.37**	**-.36**	**.29**	**-.35**	**.33**	**-.37**	**.27**	**-.37**	**.51**	-						
11. Cued Recall INCL	.10	-.11	.08	**-.14**	.10	**-.13**	-.01	-.08	**.15**	.04	-					
12. Cued Recall EXCL	-.09	.09	-.11	**.18**	**-.14**	**.19**	.01	.05	**-.15**	-.09	**-.42**	-				
13. Cued Recall Neut	.03	**-.14**	.05	-.11	.09	-.12	.05	-.11	.08	-.02	**.54**	**-.40**	-			
14. Recognition INCL	.04	-.01	.00	-.08	.06	-.04	.00	-.09	.05	-.08	**.33**	**-.25**	**.30**	-		
15. Recognition EXCL	-.01	-.03	-.03	.05	-.09	.11	-.02	.04	-.05	-.09	**-.23**	**.24**	**-.25**	.01	-	
16. Recognition Neut	.09	-.06	**.15**	**-.16**	.11	-.09	.01	**-.19**	.12	-.10	**.39**	**-.29**	**.27**	**.44**	**-.25**	-
N	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238	238
M	0.85	0.21	0.85	0.22	0.80	0.25	0.82	0.24	0.52	0.47	0.89	0.40	0.76	0.83	0.25	0.77
SD	0.11	0.12	0.09	0.12	0.11	0.12	0.13	0.15	0.16	0.12	0.08	0.15	0.11	0.11	0.15	0.15
Split-half *r*	0.65	0.69	0.55	0.61	0.55	0.63	0.77	0.68	0.69	0.56	0.23	0.39	0.20	0.43	0.54	0.54
Skew	-0.91	0.59	-0.63	0.16	-0.47	0.29	-1.61	1.19	0.00	0.21	-0.81	0.01	-0.28	-0.74	0.93	-0.75
Kurtosis	1.20	-0.16	0.04	-0.59	-0.05	-0.07	4.81	3.19	-0.30	0.03	0.21	-0.58	0.10	0.33	1.57	0.16

Table 1. Correlation matrix for measures of task performance. Bolded correlations are significant at the $p < .05$ level. INCL and EXCL signify inclusion and exclusion, respectively. ReasSpan = Reasoning Span; BPSpan = Brown-Peterson Span; OSpan = Operation Span; RSpan = Reading Span; Mem Upd = Memory Updating; Run Span = Running Memory Span; Neut = Neutral.

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. ReasSpan R	**-**													
2. ReasSpan F	**.24**	**-**												
3. BPSpan R	**.77**	**.15**	**-**											
4. BPSpan F	-.12	-.07	-.10	**-**										
5. OSpan R	**.55**	.08	**.54**	**-.18**	**-**									
6. OSpan F	.02	.07	-.01	.11	.12	**-**								
7. RSpan R	**.55**	.12	**.54**	-.05	**.51**	-.08	**-**							
8. RSpan F	-.09	-.08	-.12	**.22**	-.12	-.08	-.09	**-**						
9. Mem Upd	**.30**	.01	**.31**	-.01	**.36**	.08	**.29**	-.05	**-**					
10. Run Span	**.41**	.09	**.36**	**-.15**	**.39**	.02	**.38**	**-.14**	**.51**	**-**				
11. Cued Recall R	**.12**	.05	**.17**	-.12	**.19**	-.01	.04	**-.15**	**.18**	.08	**-**			
12. Cued Recall F	.03	-.04	-.01	-.03	.00	-.02	.03	-.02	.05	-.04	**.32**	**-**		
13. Recognition R	.01	.04	.06	-.11	.12	-.01	.06	**-.13**	.07	.02	**.41**	**.26**	**-**	
14. Recognition F	-.01	.07	-.03	-.04	-.08	-.04	-.05	-.02	-.01	-.11	.03	.04	-.09	**-**
N	238	238	238	238	238	238	238	238	238	238	238	238	238	238
M	0.63	0.61	0.63	0.60	0.55	0.57	0.58	0.56	0.52	0.47	0.49	0.80	0.58	0.58
SD	0.19	0.17	0.19	0.19	0.21	0.14	0.23	0.15	0.16	0.12	0.20	0.12	0.19	0.23
Split-half *r*	0.75	0.24	0.72	0.36	0.71	0.19	0.78	0.14	0.69	0.56	0.46	0.11	0.50	0.28
Skew	-0.61	0.18	-0.16	-0.98	-0.14	-0.28	-0.56	-0.47	0.00	0.21	-0.18	-0.37	-0.37	-0.29
Kurtosis	-0.07	0.34	-0.55	2.16	-0.58	1.97	-0.03	2.02	-0.30	0.03	-0.37	0.46	0.06	-0.25

Table 2. Correlation matrix of process estimates. R and F signify Recollection and Familiarity, respectively. Bolded correlations are significant at the $p < .05$ level.

All task performance and process estimate measures (with the exception of Reading Span inclusion and exclusion) met the standard criteria for acceptable skew (within a range of approximately +/- 2) and kurtosis (within a range of approximately +/- 2). Reliability of the performance and process estimates was less consistent. Specifically, the working memory measures and their respective recollection process estimates met the typical criteria of a Cronbach's alpha of least .70. Indeed, in some cases, Cronbach's alpha of working memory recollection exceeded that of task performance, which is impressive given that difference scores are often found to be unreliable (cf. Overall & Woodward, 1978). However, the updating and episodic memory measures in many cases approached the criterion of .70, but not consistently, and reliabilities for familiarity estimates' were consistently poor. As will be noted later, the poor reliability of the familiarity estimates may be most responsible for the failure of a familiarity factor to obtain.

Measurement Models: Task Performance

A summary of all tested models can be found in Table 3. Standard criteria were used to determine model fit: a comparative fit index (CFI) of >.90 (Hu & Bentler, 1995) and a root-mean-square-error of approximation (RMSEA) of < .10 (Brown & Cudeck, 1993). Initial measurement models using confirmatory factor analysis (CFA) were used to identify the respective factor loadings of each task to a particular latent variable. It should be noted that the most common indicators of performance were used to represent each task variable for the task performance measurement models. Thus, inclusion scores were used for the working memory tests and the inclusion and neutral performance on the episodic memory tests were averaged to compose the manifest variable for their respective tasks used in the models. The predicted measurement model is shown in Figure 1, Model A, but the alternative Models B and C, with the variability of the updating tasks loading onto a common working memory factor or one single factor (respectively), were also tested. As indicated in Table 3, a three-factor model was the best fit of the sample covariance, while two-factor ($\chi^2(2)$ difference = 33.93, $p < .01$) and single-factor measurement models ($\chi^2(3)$ difference = 81.03, $p < .01$) had significantly poorer fits in comparison (see also Figure 5). This indicates that three dissociable latent factors underlie performance on their representative tasks. See Table 4 for a comparison of the factor loadings between the different models.

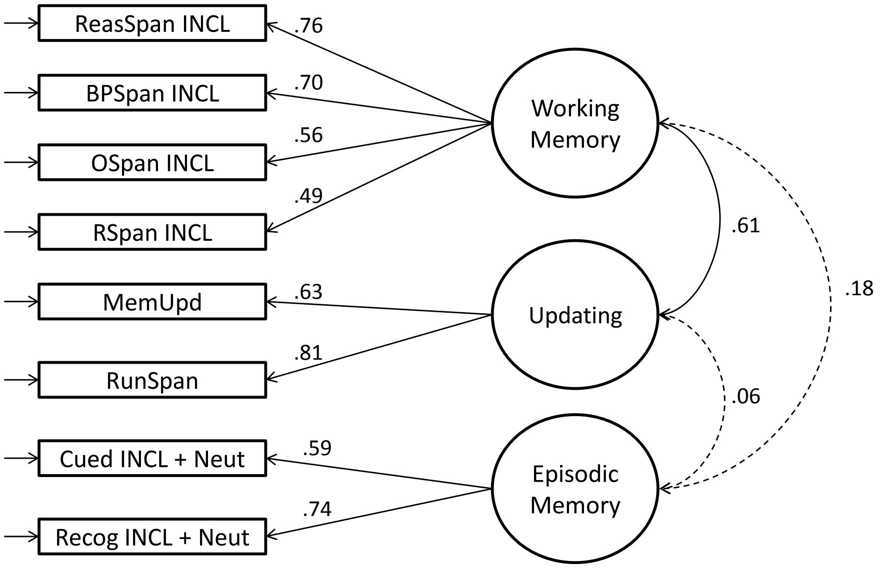

Figure 5. Three-factor measurement model of task performance.

Table 3. Models Examining Relations Among Task Performance and Process Estimates of Working Memory, Updating, and Episodic Memory.

		Factor Correlation						
Performance Measure	Model	1	2	3	χ^2	df	RMSEA	CFI
Task performance	Model 1. Three factors (see Figure 1, A)				16.08	17	0.00	1.00
	(1) Working memory	-						
	(2) Updating	.61	-					
	(3) Episodic memory	.18	.06	-				
	Model 2. Two factors (see Figure 1, B)				50.01*	19	0.08	0.91
	(1) Working memory	-						
	(2) Episodic memory	.18	-					
	Model 3. One factor (see Figure 1, C)				97.11*	20	0.13	0.78
Process Estimates	Model 1. Three factors† (see Figure 7, A)				35.44*	17	0.07	0.97
	(1) Working memory recollection	-						
	(2) Updating	.62	-					
	(3) Episodic memory recollection	.17	.13	-				
	Model 2a. Two factors† (see Figure 7, B)				72.95*	19	0.11	0.91
	(1) Working memory recollection	-						
	(2) Episodic memory recollection	.18	-					
	Model 2b. Two factors (see Figure 7, C)				79.85*	19	0.12	0.90
	(1) Recollection (WM and EM)	-						
	(2) Updating	.61	-					
	Model 3. One factor (see Figure 7, D)				117.20*	20	0.14	0.84

* Significant chi-square at the $p < .05$ level.

† Ultra-Heywood Case exhibited for Cued Recall Recollection.

Table 4. Factor loadings for the tested task performance models shown in Table 3 (excluding Model 1, which is represented in Figure 5).

Measure	Model	Task	Factor	
			1	2
Task Performance	2	ReasSpan INCL	.72	
		BPSpan INCL	.67	
		OSpan INCL	.58	
		RSpan INCL	.49	
		MemUpd	.48	
		RunSpan	.56	
		Cued INCL + Neut		.63
		Recog INCL + Neut		.69
	3	ReasSpan INCL	.72	
		BPSpan INCL	.67	
		OSpan INCL	.58	
		RSpan INCL	.49	
		MemUpd	.48	
		RunSpan	.56	
		Cued INCL + Neut	.13	
		Recog INCL + Neut	.14	

Measurement Models: Process Estimates

When decomposing working memory and episodic memory performance into process estimates of recollection and familiarity, a number of measurement models were possible (see Figure 2). The predicted model is shown in Model A, with five latent variables representing recollection and familiarity in working memory, updating, and recollection and familiarity in episodic memory. The other models shown in Figure 2 were plausible but not anticipated. When testing these models, familiarity factors in each model failed to obtain (i.e., negative factor loadings resulted; see the General Discussion for further discussion). Thus, measurement process estimates models only included recollection (see the adjusted tested models in Figure 6).

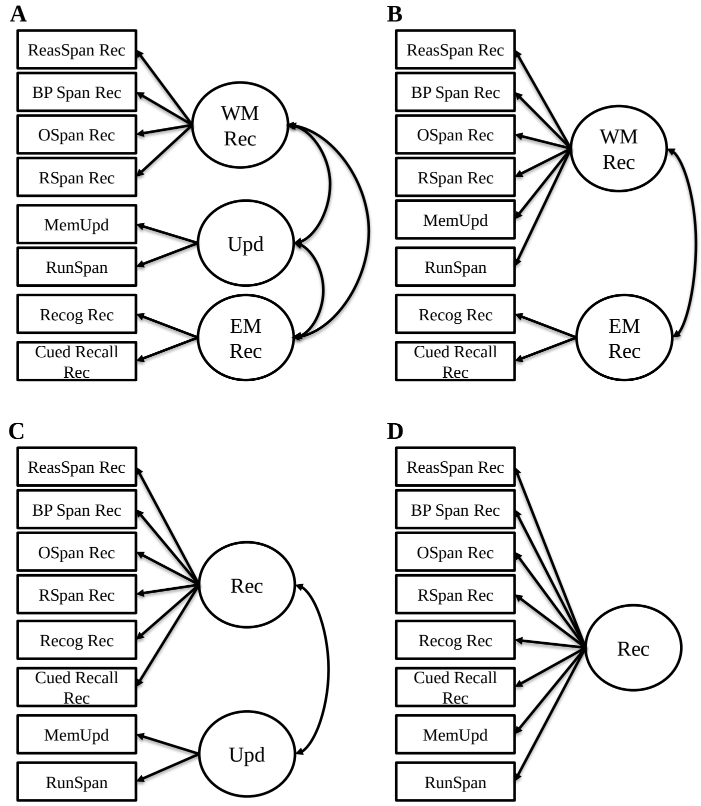

Figure 6. Adjusted models using only recollection process estimates in working memory and episodic memory (excluding familiarity).

Similar to the task performance measurement models, three-, two-, and single-factor models of recollection derived from the working memory and episodic memory tasks, in addition to updating task performance, were tested. The results of the models are presented in Table 3, with their standardized factor loadings presented in Table 5. It should be noted that Models 1 and 2a resulted in an ultra-Heywood Case (i.e., negative variance) for the cued recall task recollection and thus the solutions should be interpreted cautiously. These models were assessed using EQS, which fixes parameters and variance of Heywood Cases to 1 and 0, respectively. Models 2b and 3 did not obtain with any Heywood Case, but the indices of model fit were not sufficient according to the criteria of acceptable fit. In addition, the factor loadings of the episodic memory recollection variables were poor in these models (between .08-.19), suggesting that the origin of the Heywood Case was not due to too many factors included in the model. Despite the Heywood Case, the three-factor model had significantly superior fit compared to Model 2a ($\chi^2(2)$ difference = 36.68, $p < .01$), Model 2b ($\chi^2(2)$ difference = 43.58, $p < .01$), and Model 3 ($\chi^2(3)$ difference = 80.93, $p < .01$). When excluding the two episodic memory recollection variables from the measurement model, a two-factor model of working memory recollection and updating, $\chi^2(8) = 21.04$, $p < .01$, CFI = .98, RMSEA = .08, yielded a significantly better fit than a single-factor model, $\chi^2(9) = 58.60$, $p < .01$, CFI = .91, RMSEA = .15, $\chi^2(1)$ difference = 37.56, $p < .01$.

Table 5. Factor loadings for the tested process estimate models shown in Table 3.

			Factor		
Measure	Model	Task	1	2	3
Process Estimates	1	ReasSpan Recollection	.88		
		BPSpan Recollection	.86		
		OSpan Recollection	.66		
		RSpan Recollection	.65		
		MemUpd		.65	
		RunSpan		.78	
		Cued Recollection			1.00
		Recog Recollection			.42
	2a	ReasSpan Recollection	.87		
		BPSpan Recollection	.85		
		OSpan Recollection	.67		
		RSpan Recollection	.65		
		MemUpd	.43		
		RunSpan	.51		
		Cued Recollection			1.00
		Recog Recollection			.42
	2b	ReasSpan Recollection	.88		
		BPSpan Recollection	.86		
		OSpan Recollection	.66		
		RSpan Recollection	.65		
		MemUpd		.66	
		RunSpan		.65	
		Cued Recollection	.19		
		Recog Recollection	.09		
	3	ReasSpan Recollection	.87		
		BPSpan Recollection	.85		
		OSpan Recollection	.67		
		RSpan Recollection	.65		
		MemUpd	.42		
		RunSpan	.51		
		Cued Recollection	.19		
		Recog Recollection	.09		

Structural Equation Models

Despite the fact that the three-factor measurement models provided the best fit of the data, there were null relationships between the episodic memory latent factor and both working memory and updating latent factors. Therefore, the proposed mediation models could not be tested (see Figure 3). That is, there was no significant relationship between working memory and episodic memory for which updating may have accounted. Additionally, because updating was also unrelated to episodic memory in task performance and process estimates, the second critical step for testing mediation using structural equation modeling was not present.

CHAPTER IV

General Discussion

The results of this dissertation suggest several conclusions. First, working memory, episodic memory, and updating were separable factors at the latent level, both in task performance as well as when using recollection process estimates derived using the Process Dissociation Procedure (PDP; Jacoby, 1991). Second, dissociating recollection in working memory and episodic memory from familiarity did not facilitate understanding of the nature of the relationship between the factors compared to simply using task performance. Finally, updating may be unimportant to the relationship between working memory and episodic memory. I will discuss each of these conclusions in turn highlighting potential explanations and limitations of the current study. I will also discuss the relevant implications for models of working memory and the status of working memory as a construct of complex cognition.

Working Memory, Updating, and Episodic Memory are Distinct

The measurement models indicated that three separable factors supported task performance, and single- and two-factor models of recollection process estimates failed to provide acceptable fit of the data. Furthermore, only the working memory and updating latent factors were significantly related, whereas episodic memory was unrelated to working memory and updating. Collectively, these results suggest that working memory, updating, and episodic memory are distinct from one another at the latent level.

Such findings are somewhat inconsistent with previous studies. Regarding the separability of working memory and updating, Kane et al. (2007) showed that working memory and updating tasks were only weakly related. However, Schmiedek et al. (2009) showed that updating and working memory were indistinct at the latent level, and similarly account for variability in fluid intelligence. The current results indicate a middle-ground: working memory and updating are strongly related constructs, but not isomorphic, even when considering recollection in working memory instead of task performance. This may be due to the fact that task-specific variance distinguishes the separable latent factors supporting performance on either type of task. For example, the complex span tasks used in the current study may test updating ability, but also storage and processing (cf. Oberauer et al., 2008). Conversely, updating tasks may measure more than just the reactivation of information (e.g., substitution, transformation; Ecker, Lewandowsky, Oberauer, & Chee, 2010), and thus may not reflect a cognitive primitive (this is discussed further in the section on updating). It is unclear whether the relationship between working memory and updating reported in the current study reflects either or both of these possibilities. Future research may profit from examining the extent to which working memory and updating are supported by similar mechanisms, and whether independent variability in either construct is important to its functioning and predictive utility.

The null relationship between working memory and episodic memory was highly atypical. Working memory is consistently shown to be strongly related to episodic memory in both experimental (Johnson et al., 2002; Loaiza & McCabe, 2012; Loaiza et al., 2011; McCabe, 2008) and individual differences studies (McCabe, 2010; McCabe et al., 2010; Park et al., 1996; Unsworth & Brewer, 2009). Thus, although the study provides evidence that working memory and episodic memory are not isomorphic, the failure to demonstrate a significant relationship between the two factors departs from typical results. This lack of a relationship may have been due to the characteristics of both types of tasks. Namely, the inclusion and exclusion instructions of both tasks are not typical of tasks usually used in other latent variable analysis studies. Furthermore, the episodic memory tasks and recollection estimates were less reliable than those for working memory, which could potentially attenuate the magnitude of the true relationship between the factors (cf. Conway et al., 2005). Future studies should confirm whether these process dissociation tasks of both working memory and episodic memory load on similar, separable constructs of working memory and episodic memory as composed by typical measures of each type. Specifically, typical working memory (e.g., standard complex span tasks) and episodic memory tasks (e.g., free recall) that are not designed to derive process estimates could be included along with the process dissociation tasks used in the present study. If the typical tasks and process dissociation tasks similarly load on distinguishable but related constructs of working memory and episodic memory, it would confirm that the process dissociation tasks used in the present study did assess working memory and episodic memory performance to a similar extent as typical tasks. This would imply that the separate working memory and episodic memory latent constructs observed were not due to task-specific issues, but reflect the separable nature of the two types of memory.

Recollection and Familiarity in Working Memory and Episodic Memory

The current study provided an initial attempt to examine the relationship between working memory and episodic memory when decomposing task performance from both types of tasks into recollection and familiarity. Although a model of separable recollection factors in both types of memory was supported these factors were not strongly related, as was anticipated. However, it is of note that recollection, or controlled processing, is not a single process that supports both working memory and episodic memory performance. Rather, recollection exhibited in either type of test is distinguishable, even at the latent level. This is consistent with data from the task performance measurement models indicating that working memory and episodic memory are not supported by a unitary construct. Thus, while controlled processing may be important to successful performance in both types of tasks, it does not appear to be the same type of controlled processing regardless of the time at which a person is asked to report what they remember.

Why would controlled processing differ between working memory and episodic memory? One possibility is that working memory involves active maintenance of information, which is not required during retrieval from episodic memory (Unsworth et al., 2009). Still, the weak relationship between the two factors may indicate that recollection was not properly elicited in either or both types of tasks. However, previous research indicates that working memory and episodic memory tasks that are strongly based on recollection (e.g., free recall, McCabe et al., 2010; source memory, Unsworth & Brewer, 2009) are significantly related but not unitary in nature. Thus, despite the weak relationship in the current study between working memory and episodic memory recollection, the current study converges with previous individual differences studies supporting the two types of memory as distinct.

As stated previously, a familiarity factor failed to obtain for estimates from both working memory and episodic memory, regardless of whether the model included one or two factors of familiarity. This was most likely due to the poor reliability of the process estimate across different types of tasks (Cronbach's α ranged from .24 to .52). Given that the familiarity process estimate is meant to reflect automaticity that contributes to task performance (Jacoby 1991, 1998), it is somewhat understandable that the estimate would have poor reliability. That is, a process like familiarity may be prone to cues from the studied and tested information on a moment-to-moment basis, and thus would be less consistent compared to recollection. Furthermore, automatic processing in working memory appears to be less sensitive to individual differences in working memory capacity than more controlled processes (Engle & Kane, 2004;

Kane et al., 2001). Collectively, these possibilities suggest that familiarity does affect performance, but its contribution is not strongly consistent across a task nor is it important to other individual differences. However, such conclusions rest on a null result and are post-hoc descriptions of data. Furthermore, the problem still remains that a failure to obtain a familiarity factor renders it difficult to examine it in relation to other factors, such as recollection. Several investigators have examined familiarity as a factor of residual variability from exclusion-based tests (Oberauer, 2005; Unsworth & Brewer, 2009). These studies have shown that residual variability representing familiarity is unrelated to working memory. Thus, there is some precedent for what was expected regarding the role of the familiarity factor, but it appears that using the PDP does not allow that process to be examined at the latent level.

Updating as Binding in Working Memory

Due to the weak relationships between episodic memory and both updating and working memory, the proposed structural equation models could not be tested. Thus, the current study cannot provide any resolution on whether updating is important to the relationship between working memory and episodic memory, particularly in terms of recollection. Given recent evidence that updating in working memory may be related to binding item content to source contexts (Loaiza & McCabe, 2012; Oberauer & Vockenberg, 2009; Szmalec et al., 2010), it was anticipated that a process like recollection that requires access to contextual detail would be reliant on mechanisms in working memory that support this process. It is plausible that the weak relationships exhibited with episodic memory indicate that the tasks did not sufficiently test episodic memory ability, as discussed previously.

The finding that updating and working memory are not unitary, using either task performance or process estimates of recollection of working memory, suggests that variability in working memory is not simply the act of actively updating information. Likewise, recent evidence suggests that updating potentially involves multiple discrete functions, which may be differentially related to working memory capacity (Ecker et al., 2010). Specifically, updating the contents of working memory may not be a basic cognitive primitive, but instead may involve three component processes of retrieval, transformation, and substitution. Ecker et al. showed that substitution, in particular, was independent of working memory, while transformation and reactivation were strongly related, but still distinct, from working memory. Thus, working memory and updating tasks may be more unitary or separable to the extent that these tasks share common component processes. Furthermore, the particular component process of reactivation, or the act of refreshing previously presented information, has been specifically linked to content-context binding in working memory (Johnson et al., 2002; Loaiza & McCabe, 2012). This implies that only one of the components in updating may be related to binding in working memory, suggesting that updating task performance on its own would perhaps not sufficiently reflect binding, given that updating performance also relies on other component processes. Thus, future studies should investigate reactivation in updating, in particular, to examine its role in recollecting contextual detail in working memory and episodic memory. While other component processes of working memory may be irrelevant, reactivation may be singularly important to content-context binding in working memory, and therefore the ability to recollect contextual detail in working memory and episodic memory.

Implications for Models of Working Memory

Despite the inconclusive nature of the results, the present study does have implications for models of working memory, as well as for the construct of working memory in the broader context of cognition. Two critical findings of the study were that a) familiarity contributes to working memory and episodic memory performance, and b) familiarity was not related to working memory or episodic memory recollection. The first result supports previous research indicating that familiarity affects working memory (e.g., Oberauer, 2005; Schmiedek et al., 2009) and episodic memory (Jacoby, 1991; 1998) alike. Furthermore, the second result converges with predictions from the executive attention framework, such that individual differences in working memory are not sensitive to more automatic processes like familiarity (Engle & Kane, 2004). Thus, the control of attention is necessary to gate out interference from more automatic responses, but tasks that can be completed on the basis of automaticity should not require controlled attention. As stated in the introduction, this premise is compatible with predictions from embedded processes models of working memory (cf. Oberauer et al., 2007), such that controlled attention is necessary for mechanisms in working memory that subserve content-context binding (e.g., Naveh-Benjamin et al., 2007). Thus, the result converges with complementary predictions of both frameworks that familiarity-based responses occur during but are unrelated to working memory (Oberauer, 2005; Unsworth & Brewer, 2009), perhaps due to the lack of controlled attention necessary to bind information in working memory.

The premise of content-context binding in working memory has also been important in some embedded processes models. Namely, binding information temporarily to a source context in working memory is presumed to be vital to successful performance, as well as to the predictive utility of working memory capacity (Oberauer, 2010; Oberauer et al., 2007; 2008). Previous work has indicated that updating in working memory is related to successful content-context binding (Johnson et al., 2002; Loaiza & McCabe, 2012; McCabe, 2008; Mitchell et al., 2000). Although the present results did not permit a test of the mediating role of updating between working memory and episodic memory recollection, it has recently been suggested that updating may involve multiple functions, only one of which is specifically tied to content-context binding (i.e., reactivation of information, Ecker et al., 2010). From this perspective, reactivation of information may be vital to working memory performance but there are other functions that may also be important. Furthermore, these functions may vary in their contribution to performance depending on the type of task that is used to test working memory. Thus, the separability of working memory and updating at the latent level indicated in this study may vary according to the requirements of tasks representing either construct. This suggests that embedded processes models may need to incorporate other components of updating in order to more completely account for working memory performance. As well, distinguishing between these components may better account for the relationship between working memory capacity and other types of higher order cognition, such as episodic memory.

Conclusions

The results of the present study supported the prediction that working memory, updating, and episodic memory are distinct constructs at the latent level, in both task performance as well as process estimates of recollection in working memory and episodic memory. These data suggest that controlled processes in working memory and episodic memory are not unitary. Furthermore, updating and working memory may not be indistinct at the latent level either, potentially due to differences in recruitment of component processes in tasks of either type. These results complement an existing literature documenting the distinction between working memory and episodic memory. In addition, the novel application of the PDP to working memory measures extends this distinction to process estimates of recollection of both working memory and episodic memory.

References

Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working memory and intelligence: The same or different constructs? *Psychological Bulletin, 131*, 30-60.

Baddeley, A.D. (1986). *Working memory*. New York, NY US: Clarendon Press/Oxford University Press.

Bao, M., Li, Z., & Zhang, D. (2007). Binding facilitates attention switching within working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 959-969.

Brown, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K. A. Bollen & J. S. Long (Eds.), *Testing structural equation models* (pp. 136-162). Beverly Hills, CA: Sage.

Blalock, L. D., & McCabe, D. P. (2011). Proactive interference and practice effects in visuospatial working memory span task performance. *Memory, 19*, 83-91.

Bunting, M., Cowan, N., & Saults, J. (2006). How does running memory span work?. *The Quarterly Journal of Experimental Psychology*, *59*, 1691-1700.

Camos, V., Lagner, P., & Barrouillet, P. (2009). Two maintenance mechanisms of verbal information in working memory. *Journal of Memory and Language, 61*, 457-469.

Camos, V., Mora, G., Oberauer, K. (2010). Adaptive choice between articulatory rehearsal and attentional refreshing in verbal working memory. *Memory and Cognition, 39,* 231-244.

Chalfonte, B. L., & Johnson, M. K. (1996). Feature memory and binding in young and older adults. *Memory and Cognition, 24,* 403-416.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user’s guide. *Psychonomic Bulletin & Review, 12,* 769-786.

Cowan, N. (1993). Activation, attention, and short-term memory. *Memory and Cognition, 21,* 162-167.

Cowan, N. (1999). An embedded-processes model of working memory. In A. Miyake and P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 62-101). Cambridge: Cambridge University Press.

Daneman, M., & Carpenter, P. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning & Verbal Behavior, 19,* 450-466.

Ecker, U. K. H., Lewandowsky, S., Oberauer, K., & Chee, A. E. H. (2010). The components of working memory updating: An experimental decomposition and individual differences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*, 170-189.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11*, 19-23.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.), *The Psychology of Learning and Motivation* (Vol. 44, pp. 145-199). NY: Elsevier.

Engle, R.W., Tuholski, S.W., Laughlin, J.E., & Conway, A.R.A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128*, 309-311.

Hu, L-T., & Bentler, P. (1995). Evaluating model fit. In R. H. Hoyle (Ed.), *Structural equation modeling: Concepts, issues, and applications* (pp. 76-99). London: Sage.

Hudjetz, A., & Oberauer, K. (2007). The effects of processing time and processing rate on forgetting in working memory: Testing four models of the complex span paradigm. *Memory & Cognition*, *35*, 1675-1684.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30*, 513-541.

Jacoby, L. L. (1998). Invariance in automatic influences of memory: Toward a user's guide for the process-dissociation procedure. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 3-26.

Jacoby, L. L. (1999). Ironic effects of repetition: Measuring age-related differences in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 3-22.

Jacoby, L. L., Toth, J. P., & Yonelinas, A. P. (1993). Separating conscious and unconscious influences of memory: Measuring recollection. *Journal of Experimental Psychology: General, 122*, 139-154.

Jacoby, L. L., Wahlheim, C. N., Rhodes, M. G., Daniels, K. A., & Rogers, C. S. (2010). Learning to diminish the effects of proactive interference: Reducing false memory for young and older adults. *Memory and Cognition, 38*, 820-829.

Johnson, M. K., Reeder, J. A., Raye, C. L., & Mitchell, K. J. (2002). Second thoughts versus second looks: An age-related deficit in reflectively refreshing just-activated information. *Psychological Science, 13*, 64-67.

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General, 130*, 169-183.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General, 133*, 189-217.

Loaiza, V. M., & McCabe, D. P. (2012). Temporal contextual processing in working memory: Evidence from delayed cued recall and delayed free recall tests. *Memory & Cognition, 140*, 191-203.

Loaiza, V. M., McCabe, D. P., Youngblood, J. L., Rose, N. S., & Myerson, J. (2011). The influence of levels of processing on recall from working memory and delayed recall tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*, 1258-1263.

McCabe, D. P. (2008). The role of covert retrieval in working memory span tasks: Evidence from delayed recall tests. *Journal of Memory and Language, 58*, 480-494.

McCabe, D. P. (2010). The influence of complex working memory span task administration methods on prediction of higher level cognition and metacognitive control of response times. *Memory and Cognition, 38*, 868-882.

McCabe, D. P., & Loaiza, V. M. (2010). Recollection and familiarity estimates from working memory span tasks. Paper presented at the 51st Annual Meeting of the Psychonomic Society, St. Louis, MO.

McCabe, D. P., Roediger, H. L., & Karpicke, J. D. (2011). Automatic processing influents free recall: Converging evidence from the process dissociation procedure and remember-know judgments. *Memory and Cognition*.

McCabe, D. P., Roediger, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: Evidence for an executive attention construct. *Neuropsychology, 24,* 222-243.

Mitchell, K., Johnson, M., Raye, C., Mather, M., & D'Esposito, M. (2000). Aging and reflective processes of working memory: Binding and test load deficits. *Psychology and Aging*, *15*, 527-541.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.

Mogle, J. A., Lovett, B. J., Stawski, R. S., & Sliwinski, M. J. (2008). What’s so special about working memory? An examination of the relationships among working memory, secondary memory, and fluid intelligence. *Psychological Science, 19,* 1071-1077.

Naveh-Benjamin, M., Cowan, N., Kilb, A., & Chen, Z. (2007). Age-related differences in immediate serial recall: Dissociating chunk formation and capacity. *Memory & Cognition, 35*, 724-737.

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 411-421.

Oberauer, K. (2005). Binding and inhibition in working memory: Individual and age differences in short-term recognition. *Journal of Experimental Psychology: General, 134,* 368-387.

Oberauer, K., Süß, H.-M., Wilhelm, O., & Sander, R. (2007). Individual differences in working memory capacity and reasoning ability. In A. Conway, C. Jarrold, M. Kane, A. Miyake, & J. Towse (Eds.), *Variation in working memory* (pp. 49-75), Oxford: Oxford University Press.

Oberauer, K., Süß, H., Wilhelm, O., & Wittman, W. (2003). The multiple faces of working memory: Storage, processing, supervision, and coordination. *Intelligence, 31*, 167-193.

Oberauer, K., Süβ, H., Wilhelm, O., & Wittmann, W. W. (2008). Which working memory functions predict intelligence?. *Intelligence, 36*, 641-652.

Oberauer, K., & Vockenberg, K. (2009). Updating of working memory: Lingering bindings. *The Quarterly Journal of Experimental Psychology, 62*, 967-987.

Park, D., Smith, A., Lautenschlager, G., Earles, J., Frieske, D., Zwahr, M., et al. (1996). Mediators of long-term memory performance across the life span. *Psychology and Aging, 11*, 621-637.

Rose, N. S., Myerson, J., Roediger, H. L., & Hale, S. (2010). Similarities and differences between working memory and long-term memory: Evidence from the levels-of-processing span task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*, 471-483.

Saito, S., Jarrold, C., & Riby, D. M. (2009). Exploring the forgetting mechanisms in working memory: Evidence from a reasoning span test. *The Quarterly Journal of Experimental Psychology, 62*, 1401-1419.

Schmiedek, F., Hildebrandt, A., Lövdén, M., Wilhelm, O., & Lindenberger, U. (2009). Complex span versus updating tasks of working memory: The gap is not that deep. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*, 1089-1096.

Schmiedek, F., Li, S., & Lindenberger, U. (2009). Interference and facilitation in spatial working memory: Age-associated differences in lure effects in the n-back paradigm. *Psychology and Aging, 24,* 203-210.

Schumacker, R. E., & Lomax, R. G. (2010). *A beginner's guide to structural equation modeling*

(3rd ed.). New York, NY US: Routledge/Taylor & Francis Group.

Sederberg, P. B., Miller, J. F., Howard, M. W., & Kahana, M. J. (2010). The temporal contiguity effect predicts episodic memory performance. *Memory and Cognition, 38,* 689-699.

Szmalec, A., Verbruggen, F., Vandierendonck, A., & Kemps, E. (2010). Control of interference during working memory updating. *Journal of Experimental Psychology: Human Perception and Performance*.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28*, 127-154.

Unsworth, N., & Brewer, G. A. (2009). Examining the relationships among item recognition, source recognition, and recall from an individual differences perspective. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*, 1578-1585.

Unsworth, N., Brewer, G. A., & Spillers, G. J. (2009). There's more to the working memory capacity-fluid intelligence relationship than just secondary memory. *Psychonomic Bulletin and Review, 16*, 931-937.

Unsworth, N., & Engle, R. (2006). Simple and complex memory spans and their relation to fluid abilities: Evidence from list-length effects. *Journal of Memory and Language*, *54*, 68-80.

Unsworth, N., & Engle, R. (2008). Speed and accuracy of accessing information in working memory: An individual differences investigation of focus switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*, 616-630.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods, 37,* 498-505.

Verhaeghen, P., & Hoyer, W. J. (2007). Aging, focus switching, and task switching in a continuous calculation task: Evidence toward a new working memory control process. *Aging, Neuropsychology, and Cognition, 14,* 22-39.

Wixted, J. T. (2007). Dual-process theory and signal-detection theory of recognition memory. *Psychological Review, 114*, 152-176.

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language, 46,* 441-517.

Zhang, Y., & Verhaeghen, P. (2009). Glimpses of a one-speed mind: Focus-switching and search for verbal and visual, and easy and difficult items in working memory. *Acta Psychologia, 131*, 235-2.