

12-1-2022

## Comparing Forgetting Rates Between Pattern Separation and Item Recognition

Rhiannon N. Soriano Smith

Follow this and additional works at: <https://digitalscholarship.unlv.edu/thesesdissertations>



Part of the [Cognitive Psychology Commons](#)

---

### Repository Citation

Soriano Smith, Rhiannon N., "Comparing Forgetting Rates Between Pattern Separation and Item Recognition" (2022). *UNLV Theses, Dissertations, Professional Papers, and Capstones*. 4622. <https://digitalscholarship.unlv.edu/thesesdissertations/4622>

This Thesis is protected by copyright and/or related rights. It has been brought to you by Digital Scholarship@UNLV with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/or on the work itself.

This Thesis has been accepted for inclusion in UNLV Theses, Dissertations, Professional Papers, and Capstones by an authorized administrator of Digital Scholarship@UNLV. For more information, please contact [digitalscholarship@unlv.edu](mailto:digitalscholarship@unlv.edu).

COMPARING FORGETTING RATES BETWEEN PATTERN SEPARATION AND ITEM  
RECOGNITION

By

Rhiannon N. Soriano Smith

Bachelor of Arts – Psychology  
University of San Francisco  
2018

A thesis submitted in partial fulfillment  
of the requirements for the

Master of Arts - Psychological & Brain Sciences

Department of Psychology  
College of Liberal Arts  
The Graduate College

University of Nevada, Las Vegas  
December 2022



## Thesis Approval

The Graduate College  
The University of Nevada, Las Vegas

November 10, 2022

This thesis prepared by

Rhiannon N. Soriano Smith

entitled

Comparing Forgetting Rates Between Pattern Separation and Item Recognition

is approved in partial fulfillment of the requirements for the degree of

Master of Arts - Psychological & Brain Sciences  
Department of Psychology

Colleen Parks, Ph.D.  
*Examination Committee Chair*

David Copeland, Ph.D.  
*Examination Committee Member*

Joel Snyder, Ph.D.  
*Examination Committee Member*

Lisa Bendixen, Ph.D.  
*Graduate College Faculty Representative*

Alyssa Crittenden, Ph.D.  
*Vice Provost for Graduate Education &  
Dean of the Graduate College*

## **Abstract**

Recent theories of forgetting posit that hippocampally-based memory representations are more prone to be forgotten due to decay, while extra-hippocampal representations are more likely to be forgotten due to interference (Hardt, Nader, & Nadel, 2013; Sadeh & Pertzov, 2020). The current study examined this hypothesis by comparing the rate of forgetting between pattern separation, a hippocampally-based process, and item recognition, a process that is reliant on both hippocampal and extra-hippocampal structures. It was hypothesized that pattern separation would display more forgetting due to decay because it is a hippocampally-based process, while item recognition would display more forgetting due to interference since its processes are extra-hippocampally-dependent. Participants were tested over five consecutive days using the Mnemonic Similarity Task (Stark & Kirwan, 2019), an object recognition task that yields estimates of pattern separation and item recognition. Additionally, Wickelgren's model (1975) was fit to the data to estimate forgetting rate due to decay and interference. Results indicate that pattern separation showed more forgetting due to decay, while item recognition showed more forgetting due to interference, supporting the current hypothesis. At the group level, Wickelgren's model was able to fit the observed data and predicted future forgetting quite well. Importantly, the current study adds to the growing body of literature on forgetting and can be used to clarify mixed findings within the literature.

*Keywords:* Forgetting, pattern separation, recollection, familiarity

## **Acknowledgements**

I would like to express my appreciation to my advisor, Dr. Colleen M. Parks, whose guidance and support helped me immensely in planning, executing, and writing this thesis.

I would also like to express my appreciation to the rest of my committee: Dr. David Copeland, Dr. Joel Snyder, and Dr. Lisa Bendixen, for their time and insightful perspectives.

I am grateful to Dr. Benjamin Levy for his continued mentorship and support, and for the profound impact he has had on my academic journey.

To my lab mates and fellow graduate students Alanna, Kevin, Jackson, Blake, and Elaine: Thank you for your help, support, and friendship. You kept me sane these last few years.

I would also like to thank my research assistants Mateo and Daijiana, for their commitment and assistance with various aspects of this study. Without you, I'd probably still be collecting data.

To my family and friends, thank you for listening to me ramble, complain, and practice presenting this research for hours on end. Your enthusiasm, support, and patience were endless. I can't thank you enough.

## **Dedication**

I dedicate this thesis to my grandmothers, Juanita Soriano and Carolyn Smith. I could not have achieved this milestone in my life without your encouragement, faith, and support.

## Table of Contents

<b>Abstract.....</b>	<b>iii</b>
<b>Acknowledgements .....</b>	<b>iv</b>
<b>Dedication .....</b>	<b>v</b>
<b>List of Figures.....</b>	<b>viii</b>
<b>I. Introduction .....</b>	<b>1</b>
<b>II. Previous Theories of Forgetting .....</b>	<b>2</b>
<b>III. Recent Theories of Forgetting .....</b>	<b>4</b>
<i>Process theory of forgetting.....</i>	<i>4</i>
<i>Representation theory of forgetting .....</i>	<i>6</i>
<b>IV. Forgetting Over Different Time Intervals.....</b>	<b>9</b>
<b>V. Measuring Differences in Forgetting.....</b>	<b>11</b>
<b>VI. Current Study .....</b>	<b>13</b>
<b>VII. Method .....</b>	<b>14</b>
<i>Participants.....</i>	<i>14</i>
<i>Materials.....</i>	<i>14</i>
<i>Procedure.....</i>	<i>15</i>
<b>VIII. Results.....</b>	<b>17</b>
<i>Analyses .....</i>	<i>17</i>
<i>Item Recognition and Pattern Separation: <math>d_a</math>.....</i>	<i>18</i>
Group level results .....	18
Individual fits .....	20
<i>Item Recognition and Pattern Separation: Recollection .....</i>	<i>21</i>
Group level results .....	21
Individual fits .....	23
<i>Item Recognition and Pattern Separation: Familiarity.....</i>	<i>24</i>
Group level results .....	24
Individual fits .....	26
<i>Exploratory Analyses .....</i>	<i>27</i>
Item Recognition: Recollection vs. Familiarity .....	27
Pattern Separation: Recollection vs. Familiarity .....	27

<b>IX. Discussion .....</b>	<b>28</b>
<i>Limitations .....</i>	<i>30</i>
<i>Future Directions.....</i>	<i>32</i>
<b>X. Conclusion.....</b>	<b>34</b>
<b>References .....</b>	<b>36</b>
<b>Curriculum Vitae .....</b>	<b>41</b>



## List of Figures

Figure 1. Item Recognition and Pattern Separation Forgetting Curves: $d_a$ .....	19
Figure 2. Comparison of Item Recognition and Pattern Separation Parameters in $d_a$ .....	20
Figure 3. Item Recognition and Pattern Separation Forgetting Curves: Recollection.....	22
Figure 4. Comparison of Item Recognition and Pattern Separation Parameters in Recollection .	23
Figure 5. Item Recognition and Pattern Separation Forgetting Curves: Familiarity .....	25
Figure 6. Comparison of Item Recognition and Pattern Separation Parameters in Familiarity ...	26

## I. Introduction

Forgetting is an everyday phenomenon in which information that was once successfully encoded and could be retrieved can no longer be accessed (Frankland et al., 2013). Forgetting is often ascribed to poor or ineffective encoding strategies at memory formation, which lead to routine memory failures like forgetting important tasks, items, or information. Consequently, forgetting important information can be frustrating. However, some memory theorists argue that forgetting is adaptive. Forgetting can reduce competition among memories that can cause confusion and can facilitate better prioritization, decision making, and successful retrieval.

While the phenomenon of forgetting and its consequences have been extensively researched, it is still unclear *when* forgetting occurs and *how* the forgetting process happens. Can one type of memory be forgotten faster than another? Are other kinds of memories forgotten in different manners? To investigate these questions, we must first examine why forgetting occurs in the first place.

## II. Previous Theories of Forgetting

In its nascence, forgetting of long-term episodic memories was thought to be caused by either decay over time or interference from prior learning. However, both these theories were disconfirmed (Tulving, 1974; Wixted, 2004). The proactive interference theory suggested that forgetting occurs because old material interferes with new material and was suggested as the most likely reason as to why forgetting occurs. Nevertheless, after much research, the importance of proactive interference as being responsible for most forgetting was thrown into question, which led to research demonstrating that proactive interference as a theory for everyday forgetting was unsustainable<sup>1</sup> (Underwood, 1957; Slamecka, 1966; Tulving & Madigan, 1970). Decay over time was also deemed an unscientific idea because of its reliance on time as the sole mechanism driving forgetting. Scientists agreed that time cannot be a direct cause, as time itself is a framework within which other forces are able to act. McGeoch (1932) solidified the argument that decay cannot be a viable cause of forgetting on its own with the “positive hypothesis” of forgetting. This hypothesis suggests that time cannot cause anything directly, and that forgetting itself is not passive; rather, it is a result of active interference from interpolated events (i.e., retroactive interference). Further, it posits that forgetting is a result of two “necessary” conditions which lead to recall failure: interpolated activities, or new material interfering with old material; and altered stimulating conditions (cues), in which known content is presented differently. From this point forward, decay on its own, or “passive decay” was abandoned as an explanation of forgetting (see Wixted, 2004 for a review).

Although the passive decay and proactive interference theories of forgetting were disconfirmed as research in the field advanced, they laid the groundwork for new theories of

---

<sup>1</sup> Although proactive interference did not explain forgetting in general, retroactive interference, in which new material interferes with old, was largely ignored until recently (see below).

forgetting to develop. For example, the forgetting literature has recently considered retrieval failure due to inadequate retrieval cues, failure of memory consolidation, and retroactive interference as essential factors in explaining why forgetting occurs (Wixted, 2004).

Additionally, although decay over time, or “passive decay”, was disconfirmed and abandoned as an explanation, time-specific “active” decay theories have made a resurgence as a possible explanation for forgetting. These active decay theories suggest that there is a causal, neurobiological mechanism within the hippocampus that promotes decay of memories.

Furthermore, theories that have been gaining steam posit that active decay-based and interference-based forgetting can occur at different rates based on the type of task, process, and representation that is examined.

### **III. Recent Theories of Forgetting**

#### **Process theory of forgetting**

The memory system-dependent forgetting hypothesis (Hardt, Nader, & Nadel, 2013) focuses on memory processes and views forgetting of consolidated long-term memory as an active process that systematically removes learning-induced changes in synaptic potentiation over time. Specifically, it suggests that hippocampally-dependent memories are more prone to active decay processes because of the hippocampus' unique pattern separation properties, while memories that are extra-hippocampally-dependent are more prone to interference. This is because the hippocampus can support detailed contextual encoding required of recollection and can process representations in such a way that interference is minimized (Kim & Yassa, 2013). In other words, the hippocampus can engage in pattern separation processes, in which (mostly) non-overlapping representations are created even if they are similar. Hardt et al. (2013) argue that since pattern separation is a predominantly hippocampal process, it should be more prone to forgetting due to decay as opposed to interference.

Previous theories of decay-based forgetting relied heavily on time as the sole mechanism for forgetting. However, new theories of active decay-based forgetting propose that there is an active mechanism for decay within the hippocampus which allows the forgetting process to no longer be solely dependent on time. For example, Hardt et al. (2013) proposes that there is a specific mechanism for decay that involves pattern separation processes within the hippocampus. Since damage to the hippocampus disrupts pattern separation processes, memory retrieval then becomes dependent on the cortex, creating more interference during the retrieval process. Studies examining forgetting in patients with amnesia have generally supported this idea. These patients typically present with extensive interference because they cannot pattern separate due to

impaired medial temporal lobe (MTL) and hippocampal function. For example, patients with amnesia with hippocampal damage have been shown to forget word lists within minutes after learning; however, if rest or inactivity follows the learning period, forgetting was greatly reduced (Cowan et al., 2004; Dewar et al., 2010). These findings show that among this population, forgetting due to decay should be minimal depending on the material and the brain regions supporting the memory representations, because the regions supporting pattern separation are damaged. Instead, interference may be playing a larger role in the forgetting process among these individuals, as hippocampal damage leads to reliance on the cortex for memory retrieval, resulting in increased interference (Cowan et al., 2004; Dewar et al., 2010; Hardt et al., 2013). Studies examining patients with MTL damage that spares the hippocampus have corroborated these findings. These studies find that although patients present with MTL damage to the perirhinal cortex and adjacent areas, if the hippocampus is spared, pattern separation processes are not disrupted; in fact, memory retrieval was found to be a hippocampally-dependent process, as there was no longer cortical interference at retrieval (Argyropoulos et al., 2022; Bowles et al., 2007). Findings from Kuhlmann et al. (2020) also support the idea that there is a specific mechanism for decay within the hippocampus., showing that while interference-based forgetting does occur in associative/source memory, its effects appear later and to a lesser extent than in item memory. This finding suggests that interference is not the main component of forgetting in associative memory.

Additionally, it has been suggested that neurogenesis may be a possible “active” mechanism for decay (Hardt et al., 2013; Frankland et al., 2013; Berens et al., 2020). Hardt’s hypothesis (2013) suggests that the hippocampus is protected from interference because of pattern separation, which primarily functions in the dentate gyrus. As the dentate gyrus has been

identified as a brain area in which neurogenesis occurs, it is proposed that neurogenesis is involved in pattern separation and may also serve as a specific forgetting mechanism within the hippocampus, as the removal of newly-generated neurons within the dentate gyrus disrupts hippocampally-dependent memories while leaving memories that do not require the hippocampus unimpacted (Hardt et al., 2013). This hypothesis also provides a possible neurobiological marker for active decay, suggesting that resistance to forgetting could be due to the presence of particular NMDA receptors that depend on memory activation: If memories are no longer activated, proteins from long term potentiation induction will not be created, which leads to potentiation loss and consequentially, memory loss (Frankland et al., 2013).

Findings from Berens et al., (2020) also support this proposed mechanism, suggesting that hippocampal neurogenesis, along with other neurobiological mechanisms, may reduce the availability of independent memory traces while leaving intact the precision of still-accessible traces. Therefore, more neurogenesis will increase new learning that can disrupt memory traces in the hippocampus. Similarly, Frankland et al. (2013) propose that neurogenesis is a key regulator of decay within the hippocampus, suggesting that hippocampal neurogenesis enhances memory formation by modulating the efficiency of pattern separation. Neurogenesis would then represent a mechanism of decay that impacts all hippocampally-dependent memories, regardless of content (Frankland et al., 2013).

### **Representation theory of forgetting**

Another recent theory is the representation theory of forgetting, which posits that there are representational differences in forgetting, such that different types of memory representations are subject to different types of forgetting mechanisms (Sadeh et al., 2014, Sadeh et al., 2016; Sadeh & Pertzov, 2020). This theory relies heavily on the role of the hippocampus in memory

and forgetting and suggests that associative information is forgotten due to decay, whereas item information is less sensitive to decay and more likely to be forgotten due to interference. Associative information is more likely to be forgotten due to decay because this type of information is reliant on the hippocampus, where pattern separation occurs. Similarly, item information is more likely to be forgotten due to interference because memory for single items can be stored extra-hippocampally, throughout the cortex, making them more prone to interference.

The representation theory of forgetting focuses on the rules that govern forgetting of hippocampally-dependent information: first, that relational information reliant on the hippocampus is prone to forgetting; that the rate of forgetting is not influenced by the duration of the encoding period; that forgetting can be moderated by motivation and attention; and that forgetting leads to a gradual degradation of information as opposed to a complete loss (Sadeh & Pertzov, 2020). However, the idea that forgetting leads to a gradual degradation over time has been challenged (and see Zhang & Luck (2009) for similar debates in visual working memory). For example, results from a cued-recall task found that learning of city-distance pairs was precise immediately following learning trials, however, one-week later, participants made many misattributions, indicating that they remembered the components of the pairs, but not the pairs themselves (Lew et al., 2016). Similarly, results from an associative task between words and spatial locations found that the ability to access associations declined over time, whereas precision of the memories that were successful remained relatively stable (Berens et al., 2020). These findings suggest that there are unique process differences in forgetting: memories for associative information, reliant on the hippocampus, are typically forgotten to a lesser extent over time compared to memories for item information, which are reliant on the cortex. Though



there has been mixed evidence, there are also studies with results in support of the representation theory, showing that recollection-based memories were more prone to decay than interference over short time scales, whereas the opposite pattern was found for familiarity (Sadeh et al., 2016; Kuhlmann et al., 2020).

In a similar vein, Gamoran et al. (2020) posited that non-hippocampally based representations are likely to be forgotten due to interference from similar memories as opposed to decay. Results from this study showed that over short forgetting intervals (up to one-hour delays), contextual information was forgotten over time while item information was less affected or not affected at all by the delay, demonstrating that contextual information is sensitive to active decay-based forgetting while item information is relatively protected from it. Based on the representation theory of forgetting, this finding could be due to the brain regions in which memories are stored or processed: within the hippocampus or throughout the cortex.

The memory system-dependent forgetting hypothesis and the representation theory of forgetting align well with each other because memory for associative information (indicative of the memory system-dependent hypothesis) typically relies on the hippocampus where pattern separation mostly takes place, whereas memory for simple items (indicative of the representation theory) typically relies on both the hippocampus and surrounding cortical regions such as the perirhinal cortex, but can also be nearly fully supported by the perirhinal cortex alone. These theories show that forgetting can differ based on the process and representation being examined, however, forgetting may also differ based on the time interval being examined.

#### IV. Forgetting Over Different Time Intervals

Based on the memory system-dependent hypothesis, memory representations reliant on the hippocampus may be more dependent on decay than extra-hippocampal regions, where representations overlap more and are more subject to interference (Hardt et al., 2013). However, while it is known where decay is more likely to happen, it is unclear when this process begins. Research has shown that over short time intervals of 24 hours or less, memories can decline at different rates depending on the task being examined. When assessing long time intervals (48 hours and beyond), however, differences in forgetting rates across tasks become inconsequential. For example, Hockey and Consoli (1999) found that after 48 hours, item and associative memory declined at the same rate. When tested using a remember/know (RK) procedure<sup>2</sup> after 30 minutes, 24 hours, and 48 hours, differences in forgetting rates between item and associative information was limited to 30 minutes and 24 hours, and no difference was found after 48 hours. Similarly, no evidence of differential forgetting rates between item and source memory was found after 48 hours and up to one week after a source memory task (Borenstein and LeCompte, 1995; but see Brown & Halliday, 1991).

Studies examining process differences, such as recollection and familiarity, have also found differences in forgetting when examining different time intervals. In this context, recollection involves the retrieval of contextual information and plays a significant role in associative recognition, while familiarity is a measure of memory strength. Studies examining recollection and familiarity similarly find that any initial differences in forgetting between these two processes were tempered over long time intervals. Previous research has supported this

---

<sup>2</sup> In studies involving the RK procedure, participants are instructed to indicate whether an “old” decision they made was based on recollection or familiarity by saying “remember” or “know”, respectively.

result, showing that over short time intervals (24 hours or less) memories decline faster during item recognition tasks compared to associative recognition tasks (Hockley, 1992). Lag studies have also found that familiarity declines faster than recollection (Yonelinas & Levy, 2002). For example, in studies using the RK paradigm, recollection was found to decline faster than familiarity up to 24 hours, before both processes began to decline at similar rates after the 24-hour mark, with one study demonstrating that recollection declined at a greater rate than familiarity for up to seven days after test before evening out and declining at similar rates (Gardiner & Java, 1991; Tunney, 2010). In contrast, however, one study found that configural memory (similar to associative memory) declined faster compared to item memory for up to three months (Talamini & Goree 2012). Thus, there is mixed evidence regarding forgetting rates of recollection and familiarity after 48 hours.

## V. Measuring Differences in Forgetting

A common task used to measure pattern separation is the Mnemonic Similarity Task (MST). The MST (Kirwan & Stark, 2007; Stark et al., 2019) is an object recognition memory task designed to place strong demands on pattern separation (see Method). From this task, measures of item recognition and pattern separation can be attained. Item recognition is typically measured by the ability to recognize if an item has been seen before regardless of whether it's based on recollection or familiarity. Pattern separation is typically measured using the Lure Discrimination Index (LDI) and a comparison of old items to lure items. Currently, to our knowledge, the idea that pattern separation is more vulnerable to time-based forgetting than other memory processes has yet to be examined.

Outside of using task estimates and differences to measure forgetting, Wickelgren's (1975) model is an older qualitative model used to quantify, measure, and predict forgetting. The equation is as follows:

$$d = \lambda t^{\psi} e^{-\pi t}$$

where  $d$  represents the strength of the memory trace at retention interval  $t$  (sec),  $\lambda$  represents the degree of learning,  $\psi$  represents the rate parameter for the time-decay process, and  $\pi$  represents the rate parameter for the interference process (Wickelgren, 1975). This model makes no assumptions about brain regions or representations but offers a method to test the predictions of the theories. Importantly, this model states that both interference and decay contribute to forgetting independently of one another, however, it has not been formally tested. Therefore, results from this model can quantify and measure estimate amounts of decay and

interference present in both item and associative memory over long time scales and can be used to provide empirical evidence for the efficacy of Wickelgren's model.

## VI. Current Study

The present study focused on forgetting over longer time scales (5 days) and sought to determine whether forgetting declines at different rates between item recognition and pattern separation using the MST. Based on the current literature, it was unclear whether forgetting of memories reliant on pattern separation would differ from other memories. Therefore, it is hypothesized that associative memories (dependent on pattern separation processes) will show more forgetting due to decay and will decline at a different rate compared to item memories (extra-hippocampally dependent), which will show more forgetting due to interference. Consequentially, it is hypothesized that recollection and familiarity will also decline at different rates<sup>3</sup>. Additionally, it is hypothesized that Wickelgren's model will be able to accurately model the observed forgetting curves.

On the first day of the study, participants began the encoding phase, where they viewed images of objects and judged whether the presented object is typically found indoors or outdoors. Participants then took a recognition test for old items, new items, and similar lures using a 6-point confidence scale ranging from "Sure New" (i.e., definitely new) to "Sure Old" (i.e., definitely old). Participants were instructed to accept only exact repetitions from the encoding phase as "old" and to treat the new items and the similar lures as "new". Participants completed the test phase once a day at the same time for four consecutive days following the initial study and test session, for a total of five test sessions spaced 24 hours apart.

---

<sup>3</sup> Pattern separation is found to be highly related to recollection but is not the exact same process.

## VII. Method

### Participants

A total of 83 participants aged 18-46 ( $M = 20.6$ ) were recruited through the University of Nevada, Las Vegas (UNLV) psychology department's undergraduate subject pool and participated in the experiment. Of the 83, 13 participants did not complete full five days of the study and were excluded from the final analysis. Additionally, 10 participants were excluded from analysis as they did not meet the  $d_a$  cutoff score of 0.2 on the first day of the experiment. Finally, 34 participants were excluded from the final analysis as they had negative  $d_a$  scores ( $N = 7$  for item recognition  $d_a$ ;  $N = 27$  for pattern separation  $d_a$ ), indicating that their performance was below chance and that they were actively choosing incorrectly. After these exclusions, a total of 26 participants were included in the final analysis. A post-hoc power analysis for 26 participants indicated that an effect of Cohen's  $d = -0.535$  resulted in 84% power for  $d_a$  decay comparison between item recognition and pattern separation and that an effect size of  $d = 0.109$  resulted in 13% power for the  $d_a$  interference comparison.

### Materials

#### *I. Demographic Questionnaire*

The demographic information questionnaire was used to collect participant's gender, age, race and ethnicity, and years of education. Participants also answered questions relating to their mood and concentration, and any impairments to typical cognitive functioning.

#### *II. Mnemonic Similarity Task (MST)*

The MST (Kirwan & Stark, 2007; Stark et al., 2019) is an object recognition memory task designed to place strong demands on pattern separation. The task consists of two phases: an incidental encoding phase and a surprise memory recognition task immediately after.

Participants studied 740 objects on the first day of the experiment. Across the five test sessions, participants were tested on 222 items per day, which included 74 old items, 74 new items, and 74 similar lures that were unique to each test for a total of 1110 items across all test sessions. Five counterbalance conditions were created by randomizing all 1110 stimuli five times to create five separate randomized lists which comprised each counterbalance condition. Each list was then randomly separated into 5 blocks of 222 items, which created the test lists for each day of the study. Participants were randomly assigned to one of the five counterbalance conditions and remained in that condition for the entirety of the study.

## **Procedure**

Prior to beginning the experiment on Day 1, participants completed the informed consent and demographic questionnaire, were given a brief overview of the experiment, and read instructions to begin the encoding phase. In the encoding phase of the MST, participants were presented with images of everyday objects (e.g., hammer, flower bouquet, tableware) and asked to make a judgement on whether they think the image is typically found indoors or outdoors. After completing the encoding phase on Day 1, participants were instructed to begin the test phase. During the test phase of the MST, participants were asked to rate on a 6-point scale from “Sure New” to “Sure Old” how confident they are that the presented item was presented during the encoding phase. Participants identified each item as either ‘old’ exact repetitions of images presented during encoding; ‘new’ images not presented during study; or perceptually ‘similar’ images that are new but very similar to studied items. At the end of the test session, participants were instructed to return to the lab at the same time for the next four days to continue the experiment. The following sessions (Day 2, 3, 4, and 5) consisted of just the test phase of the MST, each over a set of items unique to that day. At the end of Day 5, participants were



debriefed, had an opportunity to ask questions related to the study, and thanked for their participation.

## VIII. Results

### Analyses

Five-point forgetting curves ( $d_a$ ) were plotted by testing participants immediately and for four days after the encoding phase of the MST, for a total of five days ( $N = 26$ ). Measures of pattern separation and item recognition were taken from participant responses from the test phases of the MST over each of the five days. Item recognition was measured as the ability to discriminate between old items and new items, while pattern separation was measured as the ability to discriminate between old items and similar lures.

Group level results were obtained by averaging  $d_a$ , recollection, and familiarity values across participants and submitting the observed values to Wickelgren's model. As these results yield only single values with no variance, group level results were not statistically analyzed. Individual fit results were obtained by submitting participants'  $d_a$ , recollection, and familiarity values to Wickelgren's model to obtain estimates of initial learning, decay, and interference. These estimates were then averaged across all participants and analyzed statistically.

Confidence data were used to calculate estimates of recollection and familiarity using the dual process signal detection (DPSD) model. Forgetting curves for item recognition  $d_a$ , pattern separation  $d_a$ , recollection, and familiarity were fit with a power-exponential function (Wickelgren, 1975) to examine how well the parameters are predicted from observed data. Bayesian paired-samples t-tests comparing the estimates of initial learning, interference, and decay for item recognition and pattern separation were performed to examine differences between the two types of recognition. Exploratory Bayesian paired-samples t-tests were conducted for recollection and familiarity, comparing decay and interference parameters. Bayes factors were interpreted based on evidence categories from Wetzels et al. (2011) and are as

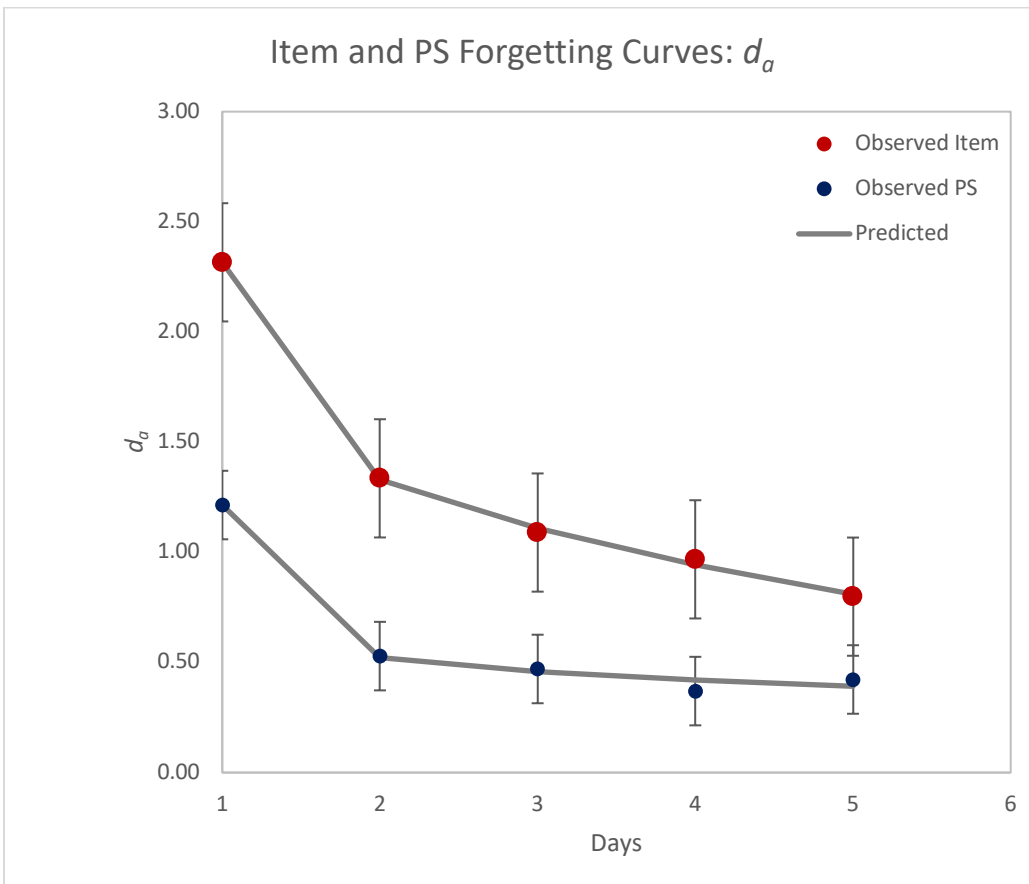
follows:  $BF = 1$ , no evidence; 1-3, anecdotal evidence for  $H_A$ ; 3-10, substantial evidence for  $H_A$ ; 10-30, strong evidence for  $H_A$ ; 30-100, very strong evidence for  $H_A$ ;  $>100$ , decisive evidence for  $H_A$ .

### **Item Recognition and Pattern Separation: $d_a$**

#### ***Group level results***

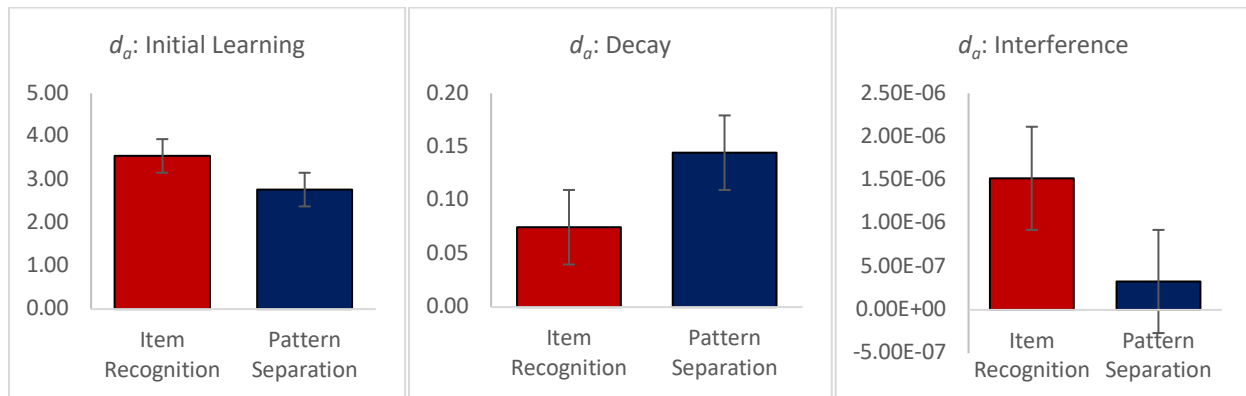
Both item recognition and pattern separation results show a marked decline in  $d_a$  from Day 1 to Day 2 before plateauing across the remaining three days. Wickelgren's model was able to fit the  $d_a$  forgetting curves for item recognition and pattern separation (Figure 1). These curves were submitted to Wickelgren's model to obtain parameters of initial learning, decay, and interference and indicated differences in item recognition and pattern separation consistent with the current hypotheses (Figure 2). Compared to pattern separation, item recognition showed overall higher initial learning. Similarly, more interference was shown in item recognition compared to pattern separation. Finally, pattern separation showed more decay compared to item recognition.

Figure 1. Item Recognition and Pattern Separation Forgetting Curves:  $d_a$



*Note.* This figure shows the forgetting decline between item recognition and pattern separation  $d_a$  across five days. The points depict the observed data while the trendline shows the predicted data from Wickelgren's model. In line with prior research, both item recognition and pattern separation decline sharply within the first 48 hours before plateauing across the remaining three days.

Figure 2. Comparison of Item Recognition and Pattern Separation Parameters in  $d_a$



*Note.* For  $d_a$ , the parameters of initial learning, decay, and interference are compared. Item recognition exhibited higher levels of initial learning and interference and lower levels of decay compared to pattern separation.

### **Individual fits**

Bayesian paired samples t-tests comparing initial learning, interference, and decay for item recognition and pattern separation were performed. Results for initial learning show strong evidence for the alternative hypothesis, indicating that item recognition has a higher level of initial learning compared to pattern separation ( $BF_{10} = 21.834$ ). Results for the interference parameter exhibited good evidence for the null hypothesis, indicating that there is no difference in interference between pattern separation and item recognition ( $BF_{01} = 4.187$ ). When examining the decay parameter, there was good evidence for the alternative hypothesis, indicating that there is a difference in decay between pattern separation and item recognition ( $BF_{10} = 4.191$ ).

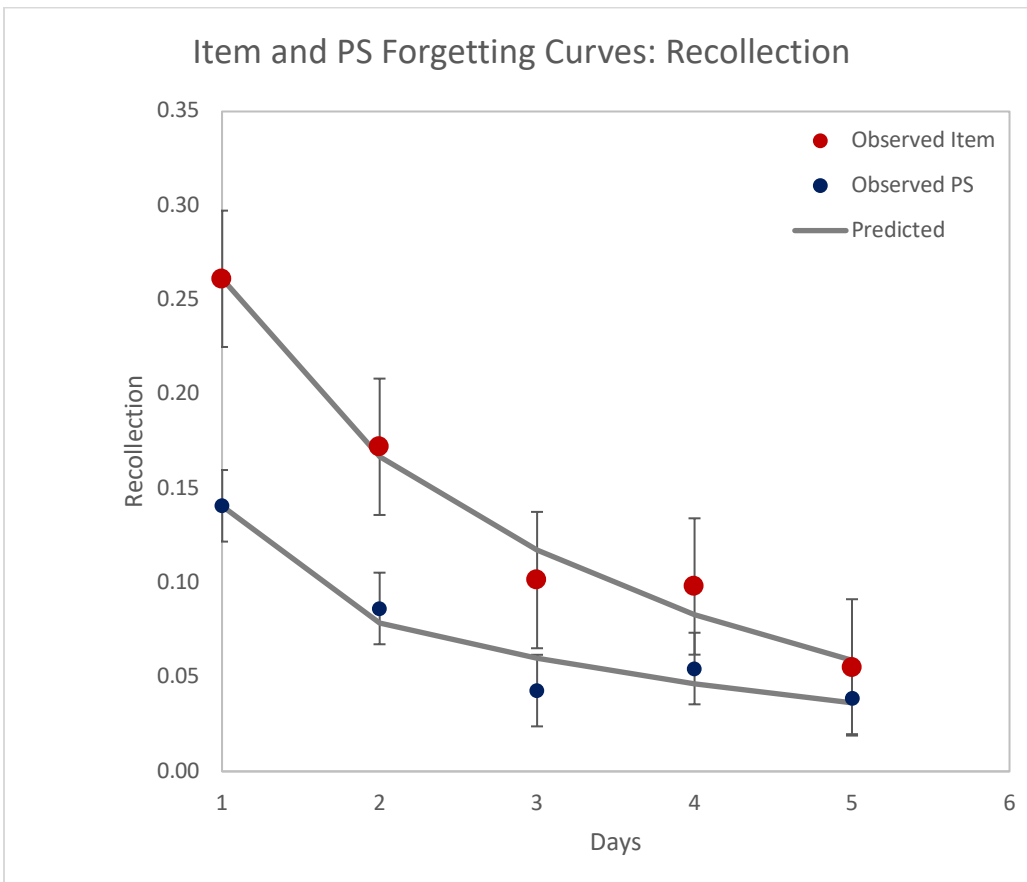
## **Item Recognition and Pattern Separation: Recollection**

### ***Group level results***

Recollection in both item recognition and pattern separation show a marked decline in recollection from Day 1 to Day 2 before plateauing across the remaining three days.

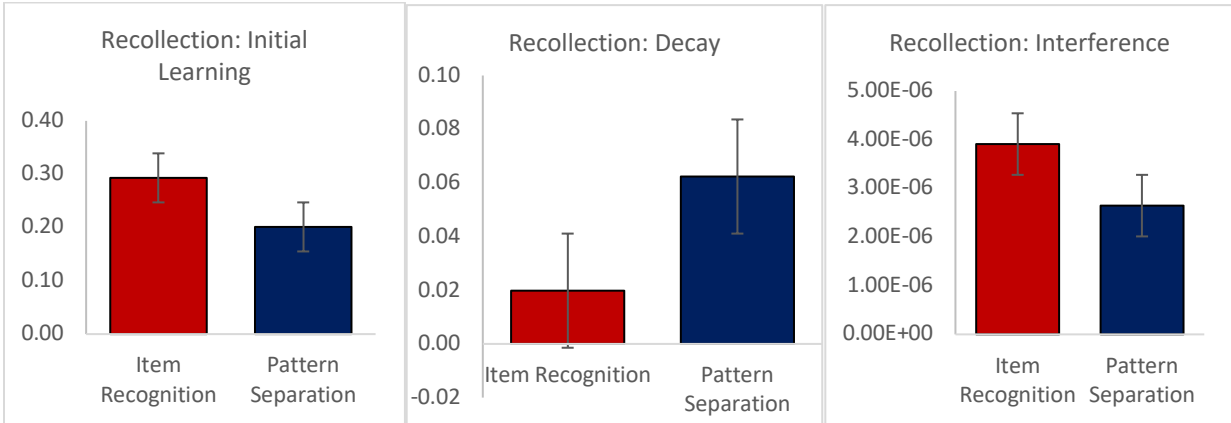
Wickelgren's model was able to accurately fit the forgetting curves for recollection for item recognition and pattern separation from the observed values (Figure 3). These curves were submitted to Wickelgren's model to obtain parameters of initial learning, decay, and interference for recollection and indicated differences in item recognition and pattern separation consistent with the present hypotheses (Figure 4). Compared to pattern separation, item recollection showed overall higher initial learning. Similarly, more interference was shown in item recollection compared to pattern separation. Finally, pattern separation showed more decay compared to item recollection.

Figure 3. Item Recognition and Pattern Separation Forgetting Curves: Recollection



*Note.* This figure shows the forgetting decline for recollection between item recognition and pattern separation across five days. The points depict the observed data while the trendline shows the predicted data from Wickelgren’s model.

Figure 4. Comparison of Item Recognition and Pattern Separation Parameters in Recollection



*Note.* For recollection, the parameters of initial learning, decay, and interference are compared. Item recognition exhibited higher levels of initial learning and interference and lower levels of decay compared to pattern separation.

### ***Individual fits***

Bayesian paired samples t-tests comparing initial learning, interference, and decay for item recognition and pattern separation for recollection were performed. Results for initial learning show weak evidence for the null hypothesis ( $BF_{01} = 2.021$ ). Results for the interference parameter show weak evidence for the alternative hypothesis, indicating that the difference between item recognition and pattern separation is ambiguous ( $BF_{10} = 1.61$ ). When examining the decay parameter, there was moderate evidence for the null hypothesis, indicating that there was no difference in decay between pattern separation and item recollection ( $BF_{01} = 4.217$ ). Overall, these findings indicate that recollection shows weak evidence for differences in item recollection compared to pattern separation; however, decay shows no difference between the two.

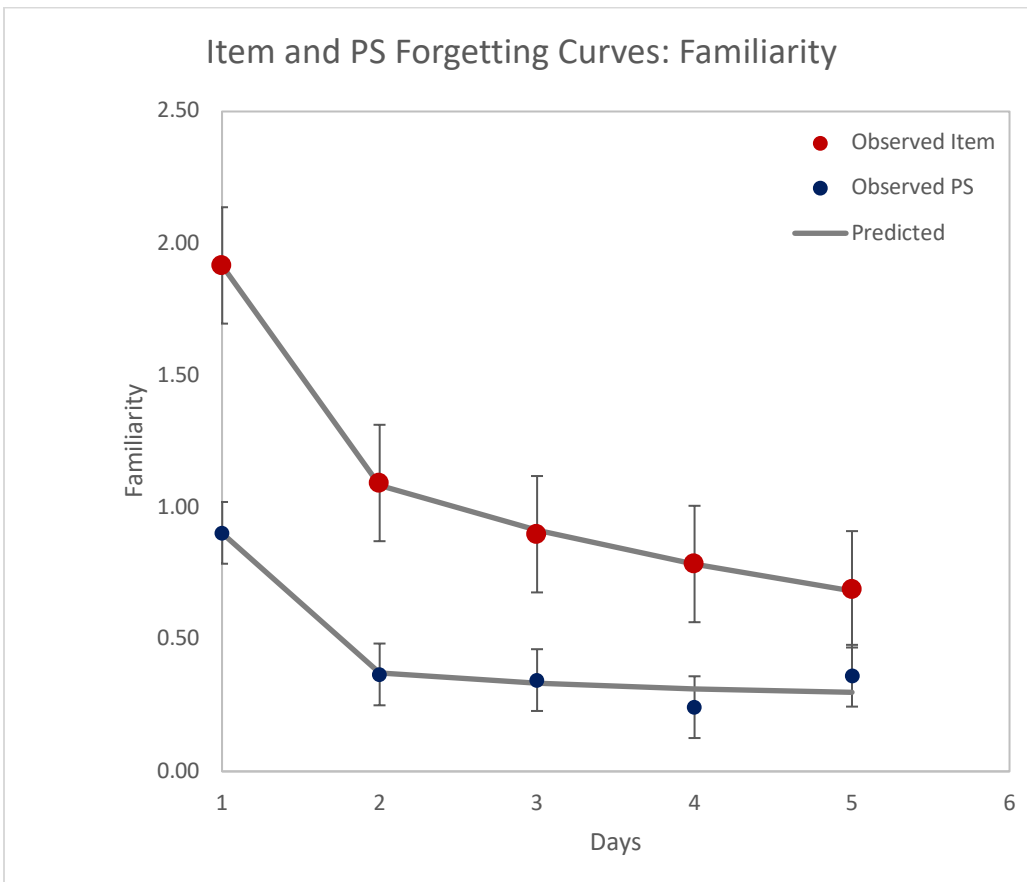


## **Item Recognition and Pattern Separation: Familiarity**

### ***Group level results***

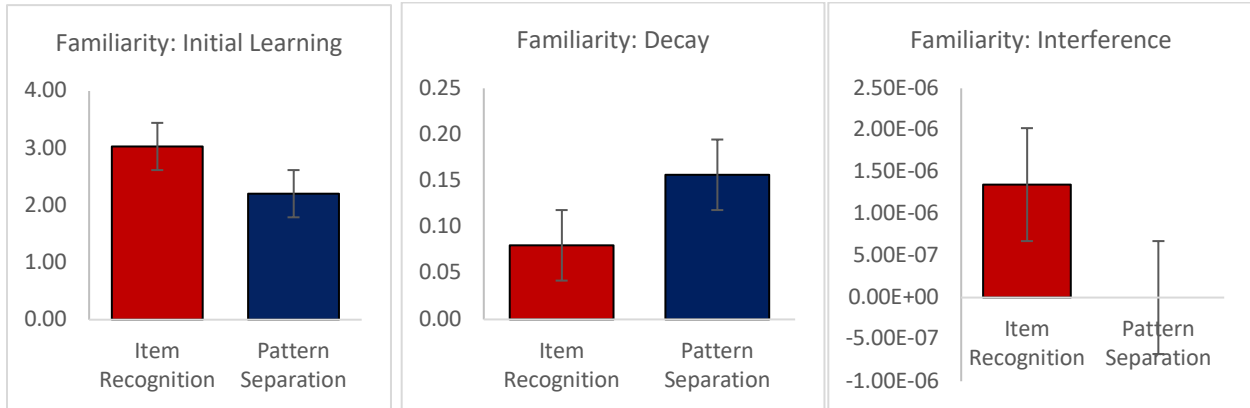
Both item recognition and pattern separation results show a marked decline in familiarity from Day 1 to Day 2 before plateauing across the remaining three days. Wickelgren's model was able to accurately model the forgetting curves for familiarity for item recognition and pattern separation from the observed values (Figure 5). These curves were submitted to Wickelgren's model to obtain parameters of initial learning, decay, and interference for familiarity and indicated differences in item recognition and pattern separation consistent with the present hypotheses (Figure 6). Compared to pattern separation, item familiarity showed higher levels of initial learning. Similarly, more interference was found in item familiarity compared to pattern separation. Finally, pattern separation exhibited more decay compared to item familiarity.

Figure 5. Item Recognition and Pattern Separation Forgetting Curves: Familiarity



*Note.* This figure shows the forgetting decline for familiarity between item recognition and pattern separation across five days. The points depict the observed data while the trendline shows the predicted data from Wickelgren's model.

Figure 6. Comparison of Item Recognition and Pattern Separation Parameters in Familiarity



*Note.* For familiarity, the parameters of initial learning, decay, and interference are compared. Item recognition exhibited higher levels of initial learning and interference and lower levels of decay compared to pattern separation.

### ***Individual fits***

Bayesian paired samples t-tests comparing initial learning, interference, and decay for item recognition and pattern separation for familiarity were performed. Results for initial learning show strong evidence for the alternative hypothesis, indicating that when examining familiarity item recognition has a higher level of initial learning compared to pattern separation ( $BF_{10} = 206$ ). Results for the interference parameter show weak evidence for the alternative hypothesis, indicating that item recognition shows numerically more interference compared to pattern separation, however, that difference is weakly supported ( $BF_{01} = 2.227$ ). When examining the decay parameter, there was weak evidence for the alternative hypothesis, indicating that there is slightly more decay in pattern separation compared to item recognition ( $BF_{10} = 2.00$ ). Thus, in contrast to the group level fits, these data show that there is only weak

evidence for differences in item recognition familiarity compared to pattern separation familiarity across the three parameters examined.

## **Exploratory Analyses**

### ***Item Recognition: Recollection vs. Familiarity***

Exploratory Bayesian paired samples t-tests were conducted for recollection and familiarity in item recognition, comparing initial learning, decay, and interference parameters between recollection and familiarity. Results for initial learning in item recognition show strong evidence for the alternative hypothesis, indicating that familiarity has higher initial learning compared to recollection ( $BF_{10} = 4e+05$ ). Results for decay in item recognition show weak evidence for the null hypothesis, indicating decay may be similar for the two processes ( $BF_{01} = 1.263$ ). Results for interference in item recognition show ambiguous evidence for the alternative hypothesis ( $BF_{10} = 1.37$ ).

### ***Pattern Separation: Recollection vs. Familiarity***

Exploratory Bayesian paired samples t-tests were conducted for recollection and familiarity in pattern separation, comparing initial learning, decay, and interference parameters between recollection and familiarity. Results for initial learning in pattern separation show strong evidence for the alternative hypothesis, indicating that familiarity has higher initial learning compared to recollection ( $BF_{10} = 533.440$ ). Results for decay in pattern separation show strong evidence for the alternative hypothesis, indicating that recollection is more subject to decay than familiarity ( $BF_{10} = 7.775$ ). Results for interference in pattern separation show strong evidence for the alternative hypothesis, indicating that recollection shows more interference than familiarity ( $BF_{10} = 12.729$ ).

## IX. Discussion

The current study sought to determine whether forgetting differs between item recognition and pattern separation over the course of five consecutive days. This experiment is the first study to use pattern separation and directly address the memory systems-dependent hypothesis (Hardt et al., 2013). Previously, it was unknown whether hippocampally-based memories are forgotten at different rates compared to memories stored extra-hippocampally, and the behavioral results from this study adds to the existing literature by suggesting that the brain region hypothesis, in which the hippocampus is a necessary part of the recollection network, is supported. Overall, the results of the study supported the proposed hypotheses: 1) that pattern separation and item recognition do decline at different rates over a five-day period; 2) that item recognition does show more interference and less decay compared to pattern separation; and 3) that Wickelgren's model is able to accurately fit and predict the observed forgetting data at the group level.

Forgetting scores for pattern separation and item recognition were found to decline over time in a way consistent with prior research on forgetting over long time scales (> 24hrs), showing that there was a marked decline in forgetting for both item recognition and pattern separation within the first 48 hours of the encoding phase before plateauing across the remaining days (Borenstein & LeCompte, 1995; Gardiner & Java, 1991; Hockley & Consoli, 1999; Tunney, 2010). Results from the current study found that item recognition and pattern separation decline differently over this period, with item recognition showing higher initial scores and an overall steeper decline compared to pattern separation. It is possible that this could be because there is more decay in pattern separation and more interference in item recognition. While it was uncertain in which direction pattern separation and item recognition would differentially decline,

the present results find that item recognition declines at a faster rate compared to pattern separation.

Similarly, results from the present study supported the hypothesis that item recognition shows more interference and less decay compared to pattern separation when examining  $d_a$ , recollection, and familiarity. Prior research has shown that item memories are stored both in the cortex and hippocampus and therefore more prone to interference compared to associative memories, which are usually only stored within the hippocampus (Hardt et al., 2013; Sadeh et al., 2014, Sadeh et al., 2016; Sadeh & Pertzov, 2020). Hippocampally-based memories are found to be more protected from interference due to pattern separation processes, which create non-overlapping representations regardless of their similarity and allow similar memories to remain separate (Kim & Yassa, 2013). This hypothesis was supported across all three variables examined, showing that item memories are more prone to interference, while associative memories are shown to be more prone to decay. This finding supports both the memory-systems dependent forgetting hypothesis (Hardt et al., 2013) and the representation theory of forgetting (Sadeh & Pertzov, 2020), which state that hippocampally-dependent memories that support associative memory are more prone to decay while extra-hippocampal memories, supportive of item memory, are more prone to interference.

Finally, to the best of our knowledge, this study was the first to test Wickelgren's model in the context of examining forgetting in both item recognition and pattern separation and found that at the group level, the model was able to fit the observed data and predict forgetting quite well. Although statistically analyzing the group results from the model is not possible, numerically, the model was able to fit the observed forgetting data neatly. However, at the individual level, the model was not able to predict and fit the observed data quite as well. This

could be due to both individual differences in participant's scores, and the noise associated with having less data to analyze at the individual level. At the group level, where there is quantitatively much more data to analyze, these small differences are flushed out, but at the individual level, fitting forgetting curves to each participant is much noisier.

The consistency in results between the present experiment and previous studies examining forgetting adds to the present literature, can aid in advancing the current theory of forgetting, and assists in teasing apart the mixed evidence within this domain. These results support both the memory-systems dependent hypothesis (Hardt et al., 2013), the representation theory of forgetting (Sadeh & Pertzov, 2020), and the use of Wickelgren's model in modelling forgetting over time.

### **Limitations**

One limitation of this study is the low sample size due to poor pattern separation performance on the MST. Of the total 83 participants in the study, 70 usable datasets were collected by the end of the data collection period. Cutoffs for  $d_a$  values for both pattern separation and item recognition on the first day of the experiment were set at  $d_a \geq 0.2$ , which led to the loss of 10 participants. An additional 34 participants were excluded from analysis due to negative  $d_a$  values on at least one of the remaining days of the study, because negative  $d_a$  values mean that the participants were actively choosing the incorrect answer: in this case, they were actively selecting that an old item was new, or that a similar lure was an old item. While most item recognition  $d_a$  values were above this cutoff, most pattern separation  $d_a$  values were not. This could be because the old and lure items (the measures of comparison for pattern separation) were too alike and therefore too difficult for participants to correctly distinguish apart, or that there simply were too many items over too long a period for participants to

correctly remember, leading to guessing as a response. Thus, another limitation of the current experiment is the possibility that the task was too difficult for some participants to complete. Prior research has supported this possibility, showing that when incoming hippocampal inputs are extremely similar, pattern separation processes will begin to fail and memory retrieval of associative information will look as though it is dependent on the hippocampus (Elfman et al., 2008). In addition, results examining forgetting using a similar task found that mnemonic discrimination was not modulated by the passage of time but by the number of stored events, suggesting that participants relied on gist-based processing when more items had been stored in memory, while they relied on a more detailed memory representation when fewer items were stored in memory (Garcia-Rueda et al., 2022). This adds support to the fact that the task at hand may have been too difficult for participants to complete successfully, which can explain the discrepancies in performance between pattern separation and item recognition.

This leads to another limitation of the current study, which is that there may not have been enough images presented. Although 1110 items were studied at encoding, that breaks down to 222 tested items each day, with only 74 of each item type (old/similar/new). That may not have been enough to detect sizable differences in pattern separation  $d_a$  scores, which could be the cause of the noisy (and negative) data within that test specifically. Furthermore, previous experiments examining associative memory using similar tasks have used thousands of items, so it may be that more items tested on the MST could lead to less noisy data at the individual level.

Finally, since the sample of participants consisted of college students, results from this experiment may not generalize across other age groups. It is possible that older adults could perform differently on the MST due to normal cognitive decline in aging, which could



potentially alter the direction of the current findings. Future studies could aim to replicate these findings across multiple age groups to validate the findings from this experiment.

### **Future Directions**

Future studies should aim to increase pattern separation  $d_a$  values to better understand the differences between pattern separation and item recognition. Poor pattern separation performance could be due to the MST being too difficult for participants. An indicator that the task may be too difficult are the negative  $d_a$  scores, which indicate that participants were actively selecting the wrong answers during the task. Indeed, most participants incorrectly identified similar lure items (which should have been selected as new) as old. The MST items are also separated into five difficulty bins, with the first few bins being the most difficult to distinguish old items from similar items, and the last bins being the easiest to distinguish. Eliminating the most difficult items from the MST will improve the task difficulty and could increase pattern separation  $d_a$  values. One thing to consider for both future directions, however, is that in trying to increase pattern separation scores, item recognition scores will also increase and could potentially reach ceiling. Future studies should ensure that item recognition score increases are also moderated in line with pattern separation.

The current study examined how different memories decline over time using a simple recognition task, however, a free recall task could also have been implemented. On the one hand, recognition tasks are easier than free recall tasks, as they contain cues. Free recall tasks, on the other hand, require the retrieval of specific information about an item without any present cues. While free recall is more difficult, results from these tasks demonstrate that even very difficult or subtly similar representations can still be stored in memory and retrieved. In the current experiment, it is possible that participants were able to differentiate and create different

representations of the MST items, but the task was just too difficult for participants to recognize those differences as actually being different. Again, decreasing the difficulty of the MST as outlined above should increase recognition and allow participants to distinguish between old, new, and similar lure items more accurately.

## X. Conclusion

Research examining how and when forgetting occurs has been studied across different tasks, processes, and representations, and has led to mixed results within the literature on this topic. The current study was the first to use pattern separation and directly address and provide support for the memory systems-dependent hypothesis posited by Hardt et al. (2013) and the representation theory of forgetting (Sadeh & Pertzov, 2020), showing that hippocampally-dependent memories (pattern separation) are more prone to decay while item memory is more prone to interference, suggesting reliance on cortical regions and less reliance on the hippocampus. Findings from this study can lead to a better understanding of the processes by which forgetting occurs. For old vs. similar lure discrimination, we find more decay and less interference because those memories are stored within the hippocampus and because they are dependent on pattern separation processes. This process creates separate representations that remain separate, and is a protective factor against interference, which can lead to faster forgetting. Indeed, this study found that item memories, which are more subject to interference, to decline at a faster rate over time compared to more associative-like memories. Similarly, this is because item memories are stored throughout the cortex and do not have protective pattern separation processes, making them more subject to interference from other memories, which consequentially, leads to faster forgetting.

Additionally, findings from this study support Wickelgren's model for predicting forgetting over time, which has not been previously tested. Results find that at the group level, Wickelgren's model can accurately fit and predict forgetting over multiple days. This finding suggests that interference and decay are separate processes. Finally, results from the current study add support and clarity to the mixed findings in the forgetting domain. While it is still

unclear at what point differences in forgetting occurs for item associative information over long time intervals (Talamini & Goree, 2012), findings from this experiment are consistent with prior research showing a difference in forgetting between the two processes within the first 48 hours before plateauing (Borenstein & LeCompte, 1995; Gardiner & Java, 1991; Hockley & Consoli, 1999; Tunney, 2010). Additionally, the findings from this experiment can lead to a better understanding of the processes by which forgetting occurs, as it adds support to the distinctions between hippocampal and extra-hippocampal memories and the processes that govern how they are forgotten. While there are still many questions to be answered involving forgetting of different memories, the current study can clarify a few questions and add support to the two most current theories in the forgetting literature.

## References

- Argyropoulos, G. P., Dell'Acqua, C., Butler, E., Loane, C., Roca-Fernandez, A., Almozal, A., ... & Butler, C. R. (2022). Functional specialization of the medial temporal lobes in human recognition memory: dissociating effects of hippocampal versus parahippocampal damage. *Cerebral Cortex*, 32(8), 1637-1652.
- Berens, S. C., Richards, B. A., & Horner, A. J. (2020). Dissociating memory accessibility and precision in forgetting. *Nature Human Behaviour*, 4(8), 866-877,
- Bornstein, B. H., & LeCompte, D. C. (1995). A comparison of item and source forgetting. *Psychonomic Bulletin & Review*, 2(2), 254-259.
- Bowles, B., Crupi, C., Mirsattari, S. M., Pigott, S. E., Parent, A. G., Pruessner, J. C., ... & Köhler, S. (2007). Impaired familiarity with preserved recollection after anterior temporal-lobe resection that spares the hippocampus. *Proceedings of the National Academy of Sciences*, 104(41), 16382-16387.
- Brown, A., & Halliday, H. (1991). Cryptomnesia and Source Memory Difficulties. *The American Journal of Psychology*, 104(4), 475-490. doi:10.2307/1422937
- Cowan, N., Beschin, N., & Della Sala, S. (2004). Verbal recall in amnesiacs under conditions of diminished retroactive interference. *Brain*, 127(4), 825-834.
- Dewar, M., Della Sala, S., Beschin, N., & Cowan, N. (2010). Profound retroactive interference in anterograde amnesia: What interferes?. *Neuropsychology*, 24(3), 357-367.  
<https://doi.org/10.1037/a0018207>
- Ekstrand, B. R. (1967). Effect of sleep on memory. *Journal of Experimental Psychology*, 75(1), 64-72. <https://doi.org/10.1037/h0024907>

- Elfman, K. W., Parks, C. M., & Yonelinas, A. P. (2008). Testing a neurocomputational model of recollection, familiarity, and source recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34(4), 752–768. <https://doi.org/10.1037/0278-7393.34.4.752>
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G\*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. <https://doi.org/10.3758/BF03193146>
- Frankland, P. W., Köhler, S., & Josselyn, S. A. (2013). Hippocampal neurogenesis and forgetting. *Trends in neurosciences*, 36(9), 497–503. <https://doi.org/10.1016/j.tins.2013.05.002>
- Gamoran, A., Greenwald-Levin, M., Siton, S., Halunga, D., & Sadeh, T. (2020). It's about time: Delay-dependent forgetting of item- and contextual-information. *Cognition*, 205, 104437. <https://doi.org/10.1016/j.cognition.2020.104437>
- García-Rueda, L., Poch, C., & Campo, P. (2022). Forgetting Details in Visual Long-Term Memory: Decay or Interference?. *Frontiers in behavioral neuroscience*, 16, 887321. <https://doi.org/10.3389/fnbeh.2022.887321>
- Gardiner, J. M., & Java, R. I. (1990). Recollective experience in word and nonword recognition. *Memory & Cognition*, 18(1), 23-30.
- Hardt, O., Nader, K., & Nadel, L. (2013). Decay happens: the role of active forgetting in memory. *Trends in cognitive sciences*, 17(3), 111–120. <https://doi.org/10.1016/j.tics.2013.01.001>

- Hockley, W. E. (1992). Item versus associative information: Further comparisons of forgetting rates. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(6), 1321–1330. <https://doi.org/10.1037/0278-7393.18.6.1321>
- Hockley, W. E., & Consoli, A. (1999). Familiarity and recollection in item and associative recognition. *Memory & Cognition*, *27*(4), 657–664. <https://doi.org/10.3758/BF03211559>
- Kim, J., & Yassa, M. A. (2013). Assessing recollection and familiarity of similar lures in a behavioral pattern separation task. *Hippocampus*, *23*(4), 287–294. <https://doi.org/10.1002/hipo.22087>
- Kirwan, C. B., & Stark, C. E. (2007). Overcoming interference: An fMRI investigation of pattern separation in the medial temporal lobe. *Learning & Memory*, *14*(9), 625–633.
- Kuhlmann, B. G., Brubaker, M. S., Pfeiffer, T., & Naveh-Benjamin, M. (2021). Longer resistance of associative versus item memory to interference-based forgetting, even in older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *47*(3), 422–438. <https://doi.org/10.1037/xlm0000963>
- Leal, S. L., Tighe, S. K., & Yassa, M. A. (2014). Asymmetric effects of emotion on mnemonic interference. *Neurobiology of learning and memory*, *111*, 41–48. <https://doi.org/10.1016/j.nlm.2014.02.013>
- Lew, T. F., Pashler, H. E., & Vul, E. (2016). Fragile associations coexist with robust memories for precise details in long-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(3), 379–393. <https://doi.org/10.1037/xlm0000178>
- McGeoch, J. A. (1932). Forgetting and the law of disuse. *Psychological Review*, *39*(4), 352–370. <https://doi.org/10.1037/h0069819>

- Sadeh, T., Ozubko, J. D., Winocur, G., & Moscovitch, M. (2014). How we forget may depend on how we remember. *Trends in cognitive sciences*, *18*(1), 26–36.  
<https://doi.org/10.1016/j.tics.2013.10.0>
- Sadeh, T., Ozubko, J. D., Winocur, G., & Moscovitch, M. (2016). Forgetting Patterns Differentiate Between Two Forms of Memory Representation. *Psychological Science*, *27*(6), 810–820. <https://doi.org/10.1177/0956797616638307>
- Sadeh, T., & Pertzov, Y. (2020). Scale-invariant Characteristics of Forgetting: Toward a Unifying Account of Hippocampal Forgetting across Short and Long Timescales. *Journal of cognitive neuroscience*, *32*(3), 386–402. [https://doi.org/10.1162/jocn\\_a\\_01491](https://doi.org/10.1162/jocn_a_01491)
- Slamecka, N. J. (1966). Differentiation versus unlearning of verbal associations. *Journal of Experimental Psychology*, *71*(6), 822–828. <https://doi.org/10.1037/h0023223>
- Stark, S. M., Kirwan, C. B., & Stark, C. (2019). Mnemonic Similarity Task: A Tool for Assessing Hippocampal Integrity. *Trends in cognitive sciences*, *23*(11), 938–951.  
<https://doi.org/10.1016/j.tics.2019.08.003>
- Talamini, L. M., & Gorree, E. (2012). Aging memories: differential decay of episodic memory components. *Learning & memory (Cold Spring Harbor, N.Y.)*, *19*(6), 239–246.  
<https://doi.org/10.1101/lm.024281.111>
- Tulving, E. (1974). Recall and recognition of semantically encoded words. *Journal of Experimental Psychology*, *102*(5), 778–787. <https://doi.org/10.1037/h0036383>
- Tulving, E., & Madigan, S. A. (1970). Memory and verbal learning. *Annual Review of Psychology*, *21*, 437–484. <https://doi.org/10.1146/annurev.ps.21.020170.002253>



- Tunney, R. J. (2010). Do changes in the subjective experience of recognition over time suggest independent processes? *British Journal of Mathematical and Statistical Psychology*, 63(1), 43-62. <https://doi.org/10.1348/000711009X416416>
- Underwood, B. J. (1957). Interference and forgetting. *Psychological Review*, 64(1), 49–60. <https://doi.org/10.1037/h0044616>
- Wetzels, R., Matzke, D., Lee, M. D., Rouder, J. N., Iverson, G. J., & Wagenmakers, E. J. (2011). Statistical evidence in experimental psychology: An empirical comparison using 855 t tests. *Perspectives on Psychological Science*, 6(3), 291-298.
- Wickelgren, W. A. (1975). Age and storage dynamics in continuous recognition memory. *Developmental Psychology*, 11(2), 165–169. <https://doi.org/10.1037/h0076457>
- Wickelgren, W. A. (1975). Alcoholic intoxication and memory storage dynamics. *Memory & Cognition*, 3(4), 385–389. <https://doi.org/10.3758/BF03212929>
- Wixted J. T. (2004). The psychology and neuroscience of forgetting. *Annual review of psychology*, 55, 235–269. <https://doi.org/10.1146/annurev.psych.55.090902.141555>
- Yonelinas, A. P., & Levy, B. J. (2002). Dissociating familiarity from recollection in human recognition memory: different rates of forgetting over short retention intervals. *Psychonomic bulletin & review*, 9(3), 575-582
- Zhang, W., & Luck, S. J. (2009). Sudden death and gradual decay in visual working memory. *Psychological science*, 20(4), 423–428. <https://doi.org/10.1111/j.1467-9280.2009.02322.x>

## Curriculum Vitae

**Rhiannon N. Soriano Smith**  
rnsorianos@gmail.com  
Department of Psychology  
University of Nevada, Las Vegas

### Education

*University of Nevada, Las Vegas*

Ph.D. Psychological & Brain Sciences, Cognitive Emphasis      Anticipated  
Advisor: Dr. Colleen Parks

*University of Nevada, Las Vegas*

M.A. Psychological & Brain Sciences, Cognitive Emphasis      2020 - 2022  
Advisor: Dr. Colleen Parks

*University of San Francisco*

B.A. Psychology, Summa Cum Laude      2014 - 2018  
Child & Youth Studies Minor

### Achievements & Awards

J. Frank Yates Student Conference Award      2022  
    Psychonomic Society  
Patricia Sastaunik Scholarship      2022  
Summer Doctoral Research Fellowship      2022  
UNLV Access Grant      2020, 2022  
UNLV GPSA Travel Award      2022  
USF Valedictorian Finalist      2018  
USF Psychology Honors      2017-2018

### Publications

Gregory, K. B., **Soriano-Smith, R. N.**, Lamp, A., Hilditch, C. J., Rempe, M. J., Flynn-Evans, E. E., & Belenky, G. L. (2021). Flight crew alertness and sleep relative to timing of in-flight rest periods in long-haul flights. *Aerospace Medicine and Human Performance*, 92(2), 83–91. <https://doi.org/10.3357/AMHP.5672.2021>

Lamp, A., Cook, M., **Soriano Smith, R. N.**, & Belenky, G. (2019). Exercise, nutrition, sleep, and waking rest? [Letter to the editor]. *Sleep*, 42(10), zsz138. <https://doi.org/10.1093/sleep/zsz138>

### **Poster Presentations**

**Soriano Smith, R. N.** & Parks, C. M. (2022) Forgetting in item recognition and pattern separation. Poster presented at the Psychonomic Society's 63<sup>rd</sup> Annual Meeting 2022.

**Soriano Smith, R. N.** & Parks, C. M. (2021) Comparing forgetting rates between pattern separation and item recognition. Poster presented at Association for Psychological Science 2021 (virtual).

**Soriano Smith, R. N.**, Lamp, A., Rasmussen, I., Basiarz, E., & Keller, C. (2020). Examining pilot safety performance indicators at critical phases of flight across multiple flight legs during commercial airline trips. Poster presented at the 2020 WSU Academic Showcase (virtual).

Lamp, A., Rasmussen, I., Cook, M., **Soriano Smith, R. N.**, Gage, N., & Belenky, G. (2019). Creating a standardized procedure for sleep measured by actigraphy in aviation field studies. Poster presented at SLEEP 2019.

Lamp, A., Gregory, K., Cook, M., **Soriano Smith, R. N.**, Rasmussen, I., Gage, N., Flynn-Evans, E., & Belenky, G. (2019). Time of day effects on sleep, fatigue, and sleepiness in flight, layover, and post-flight in short and long haul commercial aviation routes. Poster presented at SLEEP 2019.

**Soriano Smith, R. N.**, Lamp, A., Cook, M., Rasmussen, I., Gage, N., & Belenky, G. (2019). Modeling SAFTE-FAST predicted effectiveness at final top of descent: Actigraphy v. self report v. SAFTE-FAST autosleep. Poster presented at the 2019 WSU Academic Showcase.

**Soriano Smith, R. N.** & Knight, M. (2018). The effects of music familiarity on the alerting, orienting, and executive attention networks. Poster presented at the 2018 Western Psychological Association Conference.

Uchigakiuchi, T., Saito, J., Biba, T., **Soriano Smith, R. N.**, & Levy, B. J. (2017). The reliability of retrieval-induced forgetting revisited. Poster presented at the 2017 Western Psychological Association Conference.

### **Teaching Experience**

*University of Nevada, Las Vegas, Instructor*

Psychology 101; In-person and online sections

Student Research Participation (SONA) Coordinator

Fall 2022 – Present

2020 - 2021

*University of San Francisco Psychology Department, Teaching Assistant*

Research Design

Psychology Practicum

Honors Thesis Seminar

2017 - 2018

2016 - 2018

2017 - 2018

## **Research Experience**

### *Human Memory Lab (UNLV)*

Advisor: Dr. Colleen Parks

- Forgetting
- Recognition Memory

### *Occupational Sleep Medicine Group, Sleep and Performance Research Center (WSU-ESFCOM)*

Advisor: Dr. Gregory Belenky, Dr. Amanda Lamp

- Pilot sleep and performance
- Acclimation

### *Learning and Memory Lab (USF)*

Advisor: Dr. Benjamin Levy

- Retrieval-induced forgetting
- Working Memory

### *Honors Thesis Seminar (USF)*

Advisor: Dr. Marisa Knight

- Music Familiarity
- Attention

## **Professional Affiliations**

Psychonomic Society (Member)

Western Psychological Association (Graduate Student Affiliate)

Sleep Research Society (Member)

Psi Chi (Member)

## **Service**

### *UNLV Psychology Department*

Experimental Student Committee (2020-Present), President (2021-2022)

Inclusion, Diversity, Equity, Access, and Solutions (IDEAS) Committee (2020-Present)

Outreach Undergraduate Mentorship Program, Mentor (2021-Present)