March 2023

The Effects of Divided Attention in Free Recall: Affecting Trace Accumulation by Dividing Attention

Anne Olsen
University of South Florida

Follow this and additional works at: https://digitalcommons.usf.edu/etd

Part of the Cognitive Psychology Commons, and the Other Psychology Commons

Scholar Commons Citation
Olsen, Anne, "The Effects of Divided Attention in Free Recall: Affecting Trace Accumulation by Dividing Attention" (2023). USF Tampa Graduate Theses and Dissertations. https://digitalcommons.usf.edu/etd/9914

This Thesis is brought to you for free and open access by the USF Graduate Theses and Dissertations at Digital Commons @ University of South Florida. It has been accepted for inclusion in USF Tampa Graduate Theses and Dissertations by an authorized administrator of Digital Commons @ University of South Florida. For more information, please contact digitalcommons@usf.edu.
The Effects of Divided Attention in Free Recall:
Affecting Trace Accumulation by Dividing Attention

by

Anne Olsen

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts
Department of Psychology
College of Arts and Sciences
University of South Florida

Major Professor: Ken Malmberg, Ph.D.
Chad Dubé, Ph.D.
Geoff Potts, Ph.D.
Jamie Goldenberg, Ph.D.

Date of Approval:
December 5, 2022

Keywords: memory, List-Strong Effect, episodic, context

Copyright © 2023, Anne Olsen
Table of Contents

List of Figures.......................................................................................................................... v

List of Tables ............................................................................................................................ viii

List of Abbreviations ............................................................................................................. ix

Abstract ................................................................................................................................... x

Chapter One: ............................................................................................................................. 1

Introduction............................................................................................................................... 1

Chapter Two: Literature Review ............................................................................................ 2

  Encoding................................................................................................................................. 2

  Memory Traces ...................................................................................................................... 2

  Encoding Context.................................................................................................................. 3

  Buffer Processes .................................................................................................................. 4

  Strengthening Operations ..................................................................................................... 8

Retrieval .................................................................................................................................... 9

  Free Recall ........................................................................................................................... 10

  Context in Retrieval ............................................................................................................. 11

  List-Strength Effect ............................................................................................................. 13

  Attention & Memory Encoding ............................................................................................ 14

A Note on Data Analyses ......................................................................................................... 16

Chapter Three: Experiment 1................................................................................................. 18

  Experiment 1 Methods .......................................................................................................... 19

    Participants......................................................................................................................... 19

    Design ................................................................................................................................. 19

    Materials ............................................................................................................................. 20

    Procedure ........................................................................................................................... 20

      Practice Trial .................................................................................................................... 20

      Experiment ....................................................................................................................... 20

      Divided Attention Task ................................................................................................... 20

  Experiment 1 Results & Discussion ...................................................................................... 21

    Correct Recall: Long Study ............................................................................................... 21

    Correct Recall: Short Study ............................................................................................... 22

    Serial Position: Long Study ............................................................................................... 23

    Serial Position: Short Study ............................................................................................. 25

    First Recall Probability: Long Study ................................................................................ 26

    First Recall Probability: Short Study ............................................................................... 26

    Conditional Recall Probability: Long Study .................................................................... 28

    Conditional Recall Probability: Short Study .................................................................... 29

  Experiment 1 Conclusions.................................................................................................. 31

Chapter Four: Experiment 2 ................................................................................................. 34
Chapter Five: Experiment 3

Experiment 3 Results & Discussion

Serial Position

First Recall Probability

Conditional Recall Probability

Experiment 3 Conclusions

Chapter Six: Replication of Sahakyan and Malmberg (2018)
**List of Figures**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.</td>
<td>Flow of Information</td>
<td>4</td>
</tr>
<tr>
<td>Figure 2.</td>
<td>Visual Conceptualization of the Buffer</td>
<td>7</td>
</tr>
<tr>
<td>Figure 3.</td>
<td>The List Strength Effect</td>
<td>14</td>
</tr>
<tr>
<td>Figure 4.</td>
<td>Exp 1 Long Study Correct Recall</td>
<td>21</td>
</tr>
<tr>
<td>Figure 5.</td>
<td>Exp 1 Short Study Correct Recall</td>
<td>22</td>
</tr>
<tr>
<td>Figure 6.</td>
<td>Exp 1 Long Study Serial Position</td>
<td>24</td>
</tr>
<tr>
<td>Figure 7.</td>
<td>Exp 1 Short Study Serial Position</td>
<td>25</td>
</tr>
<tr>
<td>Figure 8.</td>
<td>Exp 1 Long Study First Recall Probabilities</td>
<td>27</td>
</tr>
<tr>
<td>Figure 9.</td>
<td>Exp 1 Short Study First Recall Probability</td>
<td>27</td>
</tr>
<tr>
<td>Figure 10.</td>
<td>Exp 1 Long Study Conditional Recall Probabilities</td>
<td>28</td>
</tr>
<tr>
<td>Figure 11.</td>
<td>Exp 1 Short Study Conditional Recall Probabilities</td>
<td>30</td>
</tr>
<tr>
<td>Figure 12.</td>
<td>Exp 2 Same Order Correct Recall</td>
<td>38</td>
</tr>
<tr>
<td>Figure 13.</td>
<td>Exp 2 Different Order Correct Recall</td>
<td>39</td>
</tr>
<tr>
<td>Figure 14.</td>
<td>Exp 2 Pure Lists Serial Position</td>
<td>41</td>
</tr>
<tr>
<td>Figure 15.</td>
<td>Exp 2 Mixed Lists Serial Position</td>
<td>42</td>
</tr>
<tr>
<td>Figure 16.</td>
<td>Exp 2 Pure List First Recall Probability</td>
<td>44</td>
</tr>
<tr>
<td>Figure 17.</td>
<td>Exp 2 Mixed List First Recall Probability</td>
<td>44</td>
</tr>
<tr>
<td>Figure 18.</td>
<td>Exp 2 Pure Lists Conditional Recall Probability</td>
<td>46</td>
</tr>
<tr>
<td>Figure 19.</td>
<td>Exp 2 Mixed Lists Conditional Recall Probability</td>
<td>46</td>
</tr>
<tr>
<td>Figure 20.</td>
<td>Exp 3 Same Order Correct Recall</td>
<td>54</td>
</tr>
<tr>
<td>Figure 21.</td>
<td>Exp 3 Different Order Correct Recall</td>
<td>55</td>
</tr>
<tr>
<td>Figure 22.</td>
<td>Exp 3 Pure Lists Serial Position</td>
<td>58</td>
</tr>
<tr>
<td>Figure 23.</td>
<td>Exp 3 Mixed Lists Serial Position</td>
<td>58</td>
</tr>
<tr>
<td>Figure 24.</td>
<td>Exp 3 Pure Lists First Recall Probability</td>
<td>59</td>
</tr>
</tbody>
</table>
Figure 53. Exp 4 Compared to Exp 6 Mixed Lists Serial Position .......................................................... 100
Figure 54. Exp 6 Pure Lists First Recall Probability .................................................................................. 101
Figure 55. Exp 6 Intramixed Lists First Recall Probability ....................................................................... 101
Figure 56. Exp 6 Pure Lists Conditional Recall Probability ...................................................................... 103
Figure 58. Exp 6 Combined Intramixed Lists Conditional Recall Probability .......................................... 104
Figure 57. Exp 6 Intramixed Lists Conditional Recall Probability ............................................................ 103
Figure 59. Replication Serial Position ..................................................................................................... 106
Figure 60. Replication First Recall Probability ........................................................................................ 107
Figure 61. Replication Conditional Recall Probability ............................................................................. 108

Figure A1. Full & Divided Attention Same Order Intramixed Design Serial Position ................................. 119
Figure A2. Full & Divided Attention Same Order Blocked-Mix Design Serial Position ............................ 120
Figure A3. Intramix-Pure Design Correct Recall ...................................................................................... 121
Figure A4. DO Blocked-Mix vs Intramix Design Correct Recall ............................................................... 121
Figure A5. DO Mix-Pure vs Intramixed-Pure Design CRP ....................................................................... 121
Figure A6. Different Order Intramix Lists Serial Recall ........................................................................... 122
Figure A7. Exp 2 compared to Exp 4 Correct Recall .................................................................................. 123
Figure A8. Exp 2 compared to Exp 4 Mixed Lists Serial Position .............................................................. 124
Figure A9. Exp 2 compared to Exp 4 Pure Lists Serial Position ................................................................. 124
Figure A10. Exp 2 Compared to Exp 4 Mixed Lists First Recall Probability .............................................. 125
Figure A11. Exp 2 Compared to Exp 4 Pure Lists First Recall Probability ................................................ 125
Figure A13. Exp 2 Compared to Exp 4 Mixed Lists Conditional Recall Probability .................................. 126
Figure A12. Exp 2 Compared to Exp 4 Pure Lists Conditional Recall Probability ..................................... 126
Figure 1B. IRB Exemption Letter ........................................................................................................... 127
List of Tables

Table 1. Contextual Fluctuations ........................................................................................................ 12
Table 2. Evidence Categorization for Bayes Factor Classification .................................................... 17
Table 3. Experiment 1 Design ............................................................................................................. 19
Table 4. Long Study Correct Recall .................................................................................................. 21
Table 5. Short Study Correct ............................................................................................................... 22
Table 6. Experiment 2 Design ............................................................................................................. 36
Table 7. Exp 2 Same Order Correct Recall ....................................................................................... 38
Table 8. Exp 2 Different Order Correct Recall .................................................................................. 39
Table 9. Exp 3 Design ......................................................................................................................... 51
Table 10. Exp 3 Same Order Correct Recall ...................................................................................... 54
Table 11. Exp 3 Different Order Correct Recall ................................................................................ 55
Table 12. Replication: Free Recall Correct Recall ........................................................................... 68
Table 13. Replication: Recognition d’Prime ....................................................................................... 69
Table 14. Exp 4 Correct Recall .......................................................................................................... 74
Table 15. Exp 5 Design ....................................................................................................................... 82
Table 16. Exp 5: Correct Recall ......................................................................................................... 84
Table 17. Same Order Block-Mixed and Intramixed Lists ................................................................. 92
Table 18. Exp 6 Same Order List Layout .......................................................................................... 96
Table 19. Exp 6 Different Order List Layout .................................................................................... 96
Table 20. Exp 6 correct recall .......................................................................................................... 97
Table A1. Blocked Mixed Lists and Intramixed Lists ..................................................................... 118
## List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviations</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF</td>
<td>Bayes Factor</td>
</tr>
<tr>
<td>CFM</td>
<td>Contextual Fluctuation Model</td>
</tr>
<tr>
<td>CR</td>
<td>Correct Recall</td>
</tr>
<tr>
<td>CRP</td>
<td>Conditional Recall Probability</td>
</tr>
<tr>
<td>DA</td>
<td>Divided Attention</td>
</tr>
<tr>
<td>DO</td>
<td>Different Order</td>
</tr>
<tr>
<td>Exp</td>
<td>Experiment</td>
</tr>
<tr>
<td>FA</td>
<td>Full Attention</td>
</tr>
<tr>
<td>FRP</td>
<td>First Recall Probability</td>
</tr>
<tr>
<td>IIA</td>
<td>Inter-Item Association</td>
</tr>
<tr>
<td>LS</td>
<td>Long Study</td>
</tr>
<tr>
<td>LSE</td>
<td>List-Strength Effect</td>
</tr>
<tr>
<td>LTS</td>
<td>Long-Term Store</td>
</tr>
<tr>
<td>ML</td>
<td>Mixed List</td>
</tr>
<tr>
<td>PL</td>
<td>Pure List</td>
</tr>
<tr>
<td>PS</td>
<td>Pure Strong</td>
</tr>
<tr>
<td>PW</td>
<td>Pure Weak</td>
</tr>
<tr>
<td>REM</td>
<td>Retrieving Effectively from Memory</td>
</tr>
<tr>
<td>SAM</td>
<td>Search of Associative Memory</td>
</tr>
<tr>
<td>SO</td>
<td>Same Order</td>
</tr>
<tr>
<td>SS</td>
<td>Short Study</td>
</tr>
<tr>
<td>STS</td>
<td>Short-Term Store</td>
</tr>
</tbody>
</table>
Abstract

How environmental information stores in memory directly affects our ability to retrieve the information. This thesis investigates the effects that dividing attention during study has on the storage of contextual information. Through several experiments, participants were asked to study and later recall word lists using a mixed-pure design with strengtheners varying as either repetition or study time. Experiment 1 investigates the effects of divided attention on the formation of inter-item associations and Experiments 2-6 manipulate strengthening item and context information in a memory trace when cognitive load is strained at various levels. Experimental results indicated that dividing attention during study impairs the ability of a subject to form inter-item associations and additionally dampens the ability to store trace information that can be successfully retrieved later. However, there was promising evidence showing that reducing the perceived predictability of study may help prevent against the effects of divided attention and create strong independent traces in both full and divided attention conditions.
Chapter One:
Introduction

Modern living is accompanied with continuous distraction. Be it our cell phones, the television, a nearby child or friend, our intended activities do not always receive our full and undivided attention. But what occurs with our memory formation of this intended task when we are under constant distraction? The present research is conducted with a theoretical framework originated by Atkinson & Shiffrin (1968) and extended by them and others over the past 50+ years. Like all theories of memory, it assumes that memory consists of the acquisition, representation, and retrieval of information about past events. This thesis focuses on the retrieving effectively from memory theory (REM; Shiffrin & Steyvers, 1997) in addition to frameworks developed from this theory (Malmberg & Shiffrin, 2005; Lehman & Malmberg, 2013).

When investigating the encoding process, Sahakyan & Malmberg (2018) found evidence of a reduction in acquisition of episodic information when attention was divided during the study of a list of words. Interestingly, their pattern of results indicated that information acquired while attention was divided appeared to be stored in separate memory traces even after multiple study attempts. This is a stark contrast to studying without distraction, where acquisition of episodic information stores in a single trace representing the studied word (Shiffrin & Steyvers, 1997). Sahakyan & Malmberg (2018) hypothesized that this increase in cognitive strain may have impeded the process of updating existing traces and thus increased the tendency for multiple repetitions to be represented as multiple traces. This distinct change in memory formation details an important component to understanding memory formation, particularly the development of knowledge from experience. However, it does not explain what components of memory are being disrupted during learning. The following six experiments (and one replication) investigate the findings from Sahakyan & Malmberg (2018) to determine how our attention modulates the formation and later retrieval of these memories under varying paradigms. The following sections provide relevant background information crucial for understanding the experiments.
Chapter Two:
Literature Review

Encoding

Memory is often investigated by asking subjects to study lists of stimuli (often referred to as items) and later testing their memory for the occurrence of those items. When studying a list of items, such as words, a separate episodic trace is created representing the presentation of each individual item. A trace describes a change in the memory system that occurred from the perception and encoding of an event (Tulving & Watkins, 1975). Each trace comprises of features about the item, contextual information, as well as associations including item-to-context and item-to-item (interitem) associations (Lehman & Malmberg, 2013). The process of encoding is assumed to be incomplete and error prone, as some features may not be correctly stored or stored at all. However, the more time that is spent studying an item, the more accurate and complete the episodic representation will be through the addition of more information to the trace (Atkinson & Shiffrin, 1968; Raaijmakers & Shiffrin, 1980; Shiffrin & Steyvers, 1997).

Memory Traces

Some memory models assume that memory consists of separate traces/images, each represented as a vector of feature values (Shiffrin & Steyvers, 1997). The use of a vector reflects the assumption that memory traces are multidimensional; each feature represents some aspect of what is present. Episodic images represent particular events from one’s life including both content and context, while lexical/semantic traces represent knowledge as well as the contexts in which it has been encountered or used in the past (Atkinson & Shiffrin, 1968; Shiffrin & Steyvers, 1997). According to REM (Shiffrin & Steyvers, 1997), general knowledge is assumed to be stored in vectors similar to episodic traces, however lexical/semantic memory is considered to consist of more complete and more accurate traces. For example, a lexical/semantic trace would consist of the word spelling, meanings, contexts in which it applies or was learned over a lifetime, while an episodic image would consist of the word information (e.g., spelling,
meaning) as well as the specific context encoded from that event (Shiffrin & Steyvers, 1997). In this sense, knowledge is general and decontextualized. It has been associated with a variety of different contexts during one’s lifetime which enables it to be available for use in variety of different contexts in the future.

Episodic and lexical/semantic memory traces are assumed to be permanent in some models (e.g., Raaijmakers & Shiffrin, 1981; Shiffrin & Steyvers, 1997). In the Search of Associate Memory (SAM) model, the short-term store (STS) is a temporary store of attended items, while the long-term store (LTS) is a permanent store consisting of all learned information, including prior and newly transferred information (Raaijmakers & Shiffrin, 1981). Once these traces are formed, long-term memories are assumed to be permanent but not always accessible. Inaccessible memories are thought to occur due to resulting interference from other extant memories or changes in context (Postman, 1961; Atkinson & Shiffrin, 1968; Raaijmakers & Shiffrin, 1980; Murnane & Shiffrin, 1991; Sahakyan & Kelley, 2002; Lehman & Malmberg, 2009; Lehman & Malmberg, 2013).

**Encoding Context**

Context is a theoretical construct used to describe or isolate a single past occurrence of an item (or event) that may have been encountered thousands of times. This construct describes information about the physical spatial-temporal environment, mood, or other environmental factors present when an item was experienced (Criss & Shiffrin, 2004; Malmberg & Shiffrin, 2005). For example, the testing location, the time of day, the color of the screen, and arousal levels represent possible contextual information stored during study and will aid in the process of memory retrieval. How context is stored and utilized is an important component to understanding memory formation and retrieval.

Traces for words studied within the same list will share similar contextual features but be distinct in item features for any particular word. While each word has unique physical features and meanings, words studied in the same setting will share context such as study such as location, mood of the subject, and temporal proximity (which refers to the closeness in time when two words were studied in a list). Similarities in context between traces create cohesion between words that were studied on the same list (Lehman & Malmberg, 2011; Malmberg & Shiffrin, 2005). Since similar contextual information allows for associations between traces, it act as a potential common node between item representations (Anderson & Bower, 1972; Sahakyan & Malmberg, 2018; Raaijmakers, 2003).
During the encoding process, item information will likely accumulate for as long as the item remains attended to. However, the accumulation of contextual information is not straightforward. Context described by the One-Shot Hypothesis (Malmberg & Shiffrin, 2005) is stored within a short time frame and somewhat automatically and independently from item information. Unlike item information, increases in study time during a study attempt does not always increase the amount of context stored. Results from Malmberg and Shiffrin (2005) suggests that context is fully encoded during first 1 to 2 seconds of the study attempt. Increases in study time or elaborative processing during study did not reveal effects of increased contextual storage whereas separated additional study attempts showed evidence of contextual accumulation. These results suggest that contextual information only accumulates in traces that re-enter the STS (i.e., during spaced study), whereas items that remain in the STS (i.e., during back-to-back massed study attempts) undergo only a single attempt to store context (Atkinson & Shiffrin, 1968; Shiffrin & Steyvers, 1997; Malmberg & Shiffrin, 2005).

**Buffer Processes**

![Flow of Information Diagram](image)

**Figure 1.** Flow of Information

The working-memory buffer is a cognitive control process utilized to manipulate information to accomplish the subject’s goals and task demands (Atkinson & Shiffrin, 1968; Lehman & Malmberg, 2013). Control processes typically describe cognitive behaviors such as the handling of rehearsal, informational flow, output of response, or initiation and modification of memory search (Atkinson & Shiffrin, 1969). The buffer consists of items originating from the sensory register and/or LTS, which then enter the STS (Figure 1). These contents include task goals as well as item and context information of the current environment. Item-to-context associations and associations between concurrent items (item-to-item) also form in the buffer. Item-to-item associations (i.e., interitem
associations) share very similar contextual information due to their close proximity in time of study (Atkinson & Shiffrin, 1968; Lehman & Malmberg, 2013).

While the capacity of the buffer varies among individuals, the information residing will decay within the span of 30 s if it is not actively rehearsed (Atkinson & Shiffrin, 1968, Unsworth & Engle, 2007). Additionally, the buffer is not limitless in capacity, but dynamic in size and under the control of the subject. This adaptable size of the buffer depends on the subject’s current task as well as their goals and needs (Atkinson & Shiffrin, 1968; Lehman & Malmberg 2013). Although the STS has a limited capacity for the number of items that remain in an active state, the buffer will not operate at full capacity unless directed by the subject’s goal and tasks demands. Otherwise, the use of different encoding operations may either utilize portions of the buffer or require a reduced buffer limit to be set to handle the task goal (Atkinson & Shiffrin, 1968).

While studying a list, participants often have a variety of options/strategies available to process words, such as building sentences or using imagery. The method a participant chooses is determined by task/situational demands as well as the goals of the subject (Atkinson & Shiffrin, 1968). Importantly, all controlled processing requires attentional resources to be allocated to process a word. Therefore, items attended to remain in the buffer where they can be encoded, while previously processed items were once in the subject’s focus of attention (Lehman & Malmberg, 2013).

When studying an item, the information encoded in the LTS depends on the manner in which an item is processed. For instance, when tasks require semantic processing, semantic information is more strongly encoded in the LTS, whereas if tasks require orthographic processing, the spelling of the word would be in the focus of attention and more strongly encoded in the LTS instead. In addition to affecting the content of what is encoded in the LTS, the accuracy of information transferred to long term memory is also affected by the use of different control processes. Adoption of control processes such as strategy, rehearsal, or relating new material to old have been consistently shown to create stronger associations than just the simultaneous existence of two items in the buffer (Atkinson & Shiffrin, 1968; Raaijmakers & Shiffrin, 1980). For example, Anderson (1981) explored the effects of prior knowledge on learning and retention and found that learning about fictional individuals occurred more quickly when the subject had been given prior knowledge of the character. Anderson (1981) theorized the advantage is due to subjects integrating prior knowledge of the character with new information, which facilitated learning through increasing the number and strength of connections between new and old concepts. Additionally, manipulation of the
number of items residing in the buffer appears to alter the amount/quality of information attached to each item. As modeled in Lehman and Malmberg (2013), as the number of items simultaneously rehearsed in the buffer increases, the amount of context stored in each trace decreases.

Thus, control processes increase the ability to carry out task demands of learning through the use and manipulation of the studied items. During study and due to a limited capacity buffer, the number of items needed to be maintained in the STS will likely exceed the buffer’s capacity after a certain point. When the buffer reaches capacity and new items still need to be added, existing items are either selectively and strategically chosen to be dropped (Lehman & Malmberg, 2013) or an item is dropped at random (Atkinson & Shiffrin, 1968) to make room for the new item. Depending on the goals of the subject, items may also be dropped when the buffer is not at capacity.

Figure 2 represents a visualization of the buffer during study of a list, where only a limited number of items can be attended to at any given point. Since the contents of the actual buffer cannot be directly observed, estimating the capacity of items in the STS has been derived from simulations. Previous results (Atkinson & Shiffrin, 1968; Lehman & Malmberg, 2013) suggest that under a variety of conditions the buffer capacity is often limited to two items. This two-item capacity isn’t to say more items could not be rehearsed, but that subjects often process only two items at a time (Atkinson & Shiffrin, 1968; Raaijmakers & Shiffrin, 1980; Mensink & Raaijmakers, 1988; Lehman & Malmberg, 2013).

Figure 2a represents a singular word broken down into portions of information representing contextual, item, and interitem information. Figure 2b gives an example of words presented to a subject. Figure 2c onward (discussed below) will represent the control process operations of the buffer as the subject studies these particular words.

Studying of a list begins with an empty buffer (Figure 2c) until the first word, ‘guitar’ is studied and enters the buffer (Figure 2d). As ‘guitar’ is studied, prior known lexical/semantic information is accessed and brought into the buffer where it joins other information about the physical characteristics (both old and new word information represented by the blue box) as well as other subjective contextual information present in that situation (purple box). The buffer then attempts to copy the lexical/semantic and contextual information into a new long-term trace representing this particular study attempt. At this point, the sole focus of the subject’s effort is on this first word as it is being studied by itself. When the second word, ‘bottle’, is studied, it occupies the remaining empty space of the
buffer (Figure 2e). The buffer proceeds to access known lexical/semantic information of ‘bottle’ and any new physical characteristics or contextual information are also attempted to be copied into a new trace. Since ‘bottle’ is the second word on the list, is not alone in the buffer. Thus, some lexical/semantic information about the other residing word will also be copied to the ‘bottle’ trace representing interitem associations (Shiffrin & Steyvers, 1997; Kimball, Smith, & Kahana, 2007, Xu & Malmberg, 2007). The lexical/semantic information from ‘guitar’ will be added to the end of the ‘bottle’ trace which serves an association in time when the two items were studied subsequently (shown as the striped blue portion in Figure 2e).

Figure 2. Visual Conceptualization of the Buffer
Note: a) Components of a word trace. Contextual information is represented in purple and items information is in green for the word ‘lamp’. The color of the interitem information will correspond to the word color it represents. Darker colors and longer boxes represent stronger information. b) Example word list. c) The empty buffer. d) The buffer with the first word occupying space 1. e) The second word is studied and enters space 2. f) Room for the third word is needed, and a strategic drop of the older word ‘guitar’ occurs. g) The third word ‘lamp’ now takes the empty space 1. h) ‘Bottle’ is strategically dropped. i) ‘Guitar’ takes space 2 and is studied for a second time. The original trace is reinstated in the buffer and more information is added. j) “Lamp” is dropped from space 1. k) “Bottle” enters empty space 1.

As the subject moves onto the third word, ‘lamp’, space needs to be made in the buffer. How this space is made when the buffer is full depends on the goals and strategy of the subject (Lehman & Malmberg, 2013). Figure
pictures a scenario where the subject’s goal is to study the words in order, so they drop the older word, ‘guitar’, from the buffer to make room for the next word, ‘lamp’. If the goals of the subject were to recall the first word ‘guitar’ upon completion of studying the entire list, they might instead choose to keep ‘guitar’ and drop ‘bottle’ instead. Alternatively, a random drop from the buffer is also possible (Atkinson & Shiffrin, 1968).

When the third word, ‘lamp’, enters the buffer the process continues. A copy attempt is made for contextual and item information (purple and green boxes) as well as IIA from the other existing word in the buffer (red striped box representing ‘bottle’, Figure 2g). The studying process continues with a strategic drop of the older word ‘bottle’ (Figure 2h) and ‘guitar’ reenters the buffer (Figure 2i). When ‘guitar’ is studied a second time, the trace that was created from the first study attempt (Figure 2d) is retrieved to the STS and any additional contextual, IIA, and item information available in this environment is copied to the trace making it richer with information (shown by darker information-rich boxes or extended boxes depicting new information, Figure 2i). The process continues in Figure 2j and 2k by dropping ‘lamp’ from the buffer and studying ‘bottle’ a second time.

**Strengthening Operations**

According to Craik and Lockhart (1972) the creation of the memory trace is a product of our perceptual analysis and processing methods of a stimulus. Traces that contain ample and accurate information are considered _strong_ and can be more easily recalled than traces with little or inaccurate information. This paper will focus on two strengthening methods: study time per item and the mode of repetition (distributed/spaced or massed).¹

When describing repetition types, massed study describes the process when an item is repeated back-to-back or when an item is studied once (thus, an increase in study time per item would be an increase in massed study), whereas spaced/distributed study describes the repetition of an item after a lag (or the duration filled with the study of other items). It is well known that spaced or distributed learning leads to better retention than learning which occurs in a massed fashion during a single portion of time (Hintzman, 1974 for a review). When items are

---

¹ Early predictions on success of retrieval focused on the duration of the study. These theories (e.g. (Murdock 1960; Murdock, 1962; Waugh 1967) suggested that the probability of item retention depended on the total amount of time it took for the list to be presented and was less dependent on the number item repetitions (Murdock 1962; Waugh 1967). A linear relationship between total time and number of items recalled was proposed, hypothesizing that increasing the total time studying increases the number of items recalled (supporting Ebbinghaus, 1885). However, later experiments determined that this linear relationship was not upheld for free recall. When list duration was varied, the number of items recalled was a negatively accelerated function of list duration (Atkinson & Shiffrin, 1968; Waugh, 1967; Roberts, 1972). For example, Roberts (1972) found that increasing the total time by either adding words (list length) or increasing presentation time (time studied per word) lead to decreasing gains in the number of items recalled. Increases in study time per item (rather than total study time of the list) produces better recall (Roberts, 1972) as well increasing the number of repetitions per item (Hintzman, 1974).
repeated on a list versus seen only once, for instance, the probability of subsequent recall improves (Tulving & Hastie, 1972).²

This improvement in recall is modeled in REM (Shiffrin & Steyvers, 1997) through a positive relationship between study time and stored information; an increase in a unit of study time increases the probability of storage. It is important to note that the increase in duration of study time per item increases only the storage probability of item information during a single attempt, whereas context is thought to be stored somewhat automatically and within the first 1-2 seconds of study (Malmberg & Shiffrin, 2005). Thus, an increase in study time per item increases the likelihood to store item information, but this does not share a linear relationship with the total number of items recalled.

Twice-repeated items that are spaced during study will show increases in priming of perceptual identification than when presented only once (e.g., Jacoby & Dallas, 1981). This spacing effect shows that recall probability increases as this interval (or lag) between two presentations is increased, despite an original expectation that the increase in retention intervals might predict more forgetting (Raaijmakers, 2003). Instead, as study is distributed across a period of time, the subject has increased the opportunities to sample new item and/or context information from the environment that have not been previously sampled. The study item on a subsequent presentation will likely constitute of a mixture of new and previously stored context features, and any features not already present in the trace are likely to be stored (Schooler et al., 2001). Increases in storage of information resultant from distributed study suggests that the amount of forgetting is expected to vary inversely with the duration of lag during study (Estes, 1955). Although learning typically shows to be faster initially in massed study, the overall gain of learned features is greater in spaced study (Estes, 1955a) again bolstering the beneficial effects of an increase in lag for study repetition. As repeated study occurrences increase, more specific environmental and contextual information is added, which will aid in the match of a cue to memory trace (Schooler et al., 2001).

**Retrieval**

Numerous models of memory describe memory retrieval as a probabilistic process of comparing retrieval cues to the contents of memory (e.g., Atkinson & Shiffrin, 1968; Raaijmakers & Shiffrin, 1980; Howard & Kahana,

² Increasing the number of times an item is studied often affects retention duration as well as the total amount of information stored.
2002; Lehman & Malmberg, 2013). The type of retrieval depends on the cues provided to test memory. For example, a participant in a free recall task will initially be provided with only a vague contextual cue to begin memory retrieval. Cued-recall tasks will test memory by giving cues to aid in memory retrieval, such as the beginning letter of a word or a specific category. Lastly, recognition tasks require the subject to determine if the presented material is ‘new’ or ‘old’ after studying a list of words. ‘New’ items are words not previously studied, while ‘old’ items were in the studied list (Malmberg, 2008).

**Free Recall**

A free recall test provides the subject a contextual cue to recall as many target memories (or words studied on a recent list) as possible. These open-ended questions enable the subject to utilize the given contextual cue as a means to begin their memory search. The general retrieval process as defined by SAM (Raaijmakers & Shiffrin, 1981) begins with the subject creating a plan, determining a set of cues to use, the search process (including sampling and attempts to recover any relevant memories), and the decision to continue again or cease the search. The subject will typically begin probing memory using only a context cue to recall the first word. A ‘search set’ is then chosen to narrow down the memory search to relevant images in the LTS, which then proceeds through a series of sampling and recovery attempts. Sampling is defined by a Luce choice rule, which describes the probability of sampling a specific trace as a positive function of the match between the trace and cue, and a negative function of the match between the cue and other traces (Shiffrin & Steyvers, 1997; Lehman & Malmberg, 2013). Therefore, a larger sampling probability emerges when there is a greater similarity between the cue and a specific trace and few similarities between that cue and other traces within that search set. The similarity between the retrieval cue and trace is determined by a Bayesian likelihood ratio. If a trace is successfully sampled, the subject attempts to recover it. Lastly, the recovery probability is a positive function of the number of features in the sampled trace that match the retrieval cue. Thus, since traces are often incomplete and error-prone representation of an event, the contents in some traces will be more likely to be recovered than the others (Lehman & Malmberg, 2013; Raaijmakers & Shiffrin, 1980; Shiffrin & Steyvers, 1997). Once the word is recovered, the process continues with the next memory probe possibly including both context and the just-recalled word as the cues. This process will repeat itself until a stopping parameter has been reached for either that word (wherein the process begins again with only a context cue)
or in total retrieval (the process of the free recall task ends) (Lehman & Malmberg, 2013; Raaijmakers & Shiffrin, 1980; Shiffrin & Steyvers, 1997).

**Context in Retrieval**

Context is an important component during the process of memory retrieval. In free recall, a self-generated contextual cue is used to probe and isolate a subset of memory traces in the LTS. Contextual information in the cue is compared to existing traces and traces that contain more similarities result in a greater sampling probability. Larger sampling probabilities for these traces lead to greater probabilities for recovery and subsequent retrieval. Thus, a strong factor in initial retrieval success is largely dependent on the similarity between the contents of the memory cue and target traces (Annis et al., 2013; Raaijmakers & Shiffrin, 1980; Shiffrin & Steyvers, 1997). For example, greater retrieval success is predicted when similarities increase between a self-generated context cue and the study context indicating that reinstating more accurate study context will benefit memory retrieval. Effects of context-dependent internal states (e.g. Eich, 1980; Ucros, 1989) as well as external states (e.g. Godden & Baddeley, 1975) also show that a high correspondence between incidental/background stimuli in the study and test conditions (i.e. context) often results in enhanced recall (Sahakyan & Kelley, 2002). Therefore, if successful sampling and recovery is dependent on the number of features that match between a trace and a cue, using context stored at the time of study as the cue should lead to more successful retrieval than simply using context at test (Raaijmakers & Shiffrin, 1980).

Alternatively, the process of forgetting is often attributed to large changes in context; the context at test often varies considerably from the study context. Estes (1955) described context change resultant from constant fluctuations in environmental stimuli. All present elements cannot be viewed at once due to limited processing power and capacity (Schneider & Shiffrin, 1968), therefore only a small random subset from the environment is activated at a given time. This random fluctuation is an interchange between a set of temporarily active and a set of inactive contextual elements. When an element fluctuates into an active state (or the current context) during study, they are able to be encoded (Estes, 1955). The time-dependent nature of element fluctuation means that the ‘set’ of active elements is not always the same, so by nature these elements are variable and independent at different points (Mensink& Raaijmakers, 1989). The Contextual Fluctuation Model (CFM) (Mensink & Raaijmakers, 1989) explains context change through these time-dependent changes in recall and builds upon Estes (1955). As items are
studied sequentially, the active elements for item $n$ will randomly fluctuate into inactive and active states during the interval between the $n$ and $n+1$. The elements active during study of the $n+1$ item will likely include both some of residual elements still present from item $n$ (shared active elements) as well as newly active elements that were inactive during the study of item $n$. Since contextual features are assumed to gradually fluctuate as time progresses, additional presentations of a word increases the probability that different sets of active contextual elements will be stored to the trace when a greater delay between spaced presentations occurs (Mensink & Raaijmakers, 1989; Raaijmakers, 2003). Raaijmakers (2003) combined the CFM and SAM models creating plausible explanations for this effect of spacing on contextual accumulation. Twice presented spaced items had double the amount of ‘stored’ context as the twice presented massed item. Table 1 visually presents this concept. For example, over a long retention interval, one item could be presented twice (either massed or spaced) or two items could be presented once each (via massed/back-to-back or spaced out). The contextual features stored for one item presented twice back-to-back (massed) would encode half of the contextual features than if the second presentation was spaced apart from the first (e.g., massed features '$x_1, x_2, x_3, x_4'$ or spaced features '$x_1, x_2, x_3, x_4 + x_5, x_6, x_7, x_8'$). In contrast, two different items presented once back-to-back would share contextual similar features (e.g., '$x_1, x_2, x_3, x_4'$), yet spaced presentations would yield different encoded features for each item (e.g., '$x_1, x_2, x_3, x_4'$ and '$x_5, x_6, x_7, x_8'$) (Raaijmakers, 2003). Distributing study of items over time should allow for storage of traces with more diverse contextual features than would massing study due to continuous fluctuations of contextual elements during this spacing interval.

<table>
<thead>
<tr>
<th>Table 1. Contextual Fluctuations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available environmental contextual elements: $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8$</td>
</tr>
<tr>
<td>One item presented twice</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Two items presented once</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**adapted from (Raaijmakers, 2003)**

The One-Shot Hypothesis (Malmberg & Shiffrin, 2005) refines this concept of how additional contextual information is stored in a trace. When an item is massed, studying beyond 2 s does not show effects of increases in the amount of context stored, thus only a fixed ‘sum’ of contextual information can be stored during that time. When an item is spaced, it leaves the STS and reenters upon the additional presentation, the initial moments.
(roughly between 1-2 s) lead to another attempt to store contextual information in the trace. Thus, each additional study attempt of at least 2 s will likely lead to an increase in the amount of stored contextual information, whereas increasing study time or increasing the depth of processing will not (Malmberg & Shiffrin, 2005).

The contextual fluctuations of available features throughout the course of study as well as their difference between study and test can lead to mismatches between a cue and stored traces while sampling under the assumptions of SAM (Sahakyan & Kelley, 2002). Thus, the most efficient cue to garner successful retrieval would be one that reinstates similar study context rather than a cue that uses the context readily available at test (Raaijmakers & Shiffrin, 1980).

**List-Strength Effect**

A List-Strength Effect (LSE) is observed when the tendency to remember certain items is affected by the strength of other items on a list. This effect is produced experimentally using a mixed-pure paradigm consisting of items of at least two different levels of strength manipulated by repetition, study time, or levels of processing.

Three list types (pure weak (PW), pure strong (PS), and mixed) are studied each containing the same number of different words. A PW list consists of items of all weak strength, such as 20 words studied once. A PS list comprises of all strong items, such as 20 words studied multiple times. Mixed lists consist of both strong and weak items, such as a 20-item list with 10 strong words and 10 weak words (Malmberg & Shiffrin 2005; Ratcliff et al, 1990; Sahakyan et al., 2014). This mixed-pure paradigm produces a positive (+) LSE (Figure 3) when strong words are better recalled from a mixed than pure list, while weak words are better recalled from a PW than PS list; thus, the presence of stronger words on mixed lists interferes with the retrieval of weaker items. This decrease in retrieval of weaker items when other list items are strengthened is typically found in free recall tests when item strength is manipulated by spaced repetition (whereas a slightly less positive LSE occurs in cued recall). Alternatively, the opposite pattern results in a negative (-) LSE (Figure 3), where weak words are better retrieved when mixed with strong words than when in a pure list. This pattern where word strength facilitates the retrieval of other weaker list items is commonly observed in recognition tasks (Malmberg & Shiffrin, 2005; Ratcliff et al, 1990, Shiffrin et al., 1990).

---

3 Strength describes the outcome of the trace representing a studied item, where a stronger trace would be more complete and accurate than a weaker, incomplete, and inaccurate trace.
When memory is tested via free recall, SAM predicts a +LSE. During recall, since images in memory are sampled with replacement in proportion to their strength, stronger traces will interfere or suppress the weak traces in memory from the same list (Malmberg & Shiffrin, 2005; Ratcliff et al., 1990). Stronger traces are predicted to be sampled over weaker traces due to the heavy reliance on contextual cues in free recall. These cues will sample traces with a larger likelihood (i.e., traces that contain more features matching features in the cue). In contrast, a null or slightly −LSE is typically observed in recognition when the strengthening of some items does not interfere or harm performance for other items on the list. This pattern of results is explained by differentiation (Murnane & Shiffrin, 1991; Ratcliff et al., 1990; Shiffrin et al., 1990). As traces strengthen and become more accurate and complete representations of what the subject encountered, the probability of a match between the item and contextual features in the test cue (if it’s a previously studied item) and the memory trace increases, while the number of mismatching features between cue and other stored traces decreases. Since activation of a trace different from the cue decreases as traces are strengthened, these stronger more complete and accurate traces become more dissimilar to other traces (Murnane & Shiffrin, 1991a; Ratcliff et al., 1990; Shiffrin et al., 1990, Shiffrin & Steyvers, 1997; Criss & McClelland 2006).

![Figure 3. The List Strength Effect](image)

**Attention & Memory Encoding**

The addition of a secondary task during the learning process is well known to have an effect on later recall processes. Tasking participants to simultaneously perform a second activity during encoding or retrieval is known as a dual-task paradigm and introduces additional strain on cognitive resources. Interestingly, different effects are observed when this additional task is performed during study or during recall. While dividing attention during the retrieval process appears to disrupt recall only slightly, retrieval is greatly affected when attention is divided during
the encoding process (e.g., Baddeley et al., 1984; Craik et al., 1996). This addition of a secondary task during encoding also typically shows a trade-off between successful recall and the difficulty of the additional task (Anderson & Craik, 1974; Baddeley et al., 1984; Sahakyan & Malmberg, 2018), or in other words, as intensity of the secondary task increases, recall performance often decreases.

When attention is divided among tasks during encoding, a large reduction in memory performance is often observed along with impairments occurring in item, context, and interitem information in memory (Naveh-Benjamin et al., 2003; Sahakyan & Malmberg, 2018). Since the probability of sampling a trace is determined by an associative strength between the probe cue and the trace compared with the strength of all the other traces to the probe cue (Raaijmakers & Shiffrin, 1980; Shiffrin & Steyvers, 1997), the disruption of information resultant from dividing attention will likely impair the sampling process during recall (Sahakyan & Malmberg, 2018). Additionally, elaborate methods used while studying are not spared from the disruption resultant from dividing attention. Deep-level processing methods during encoding while attention is divided produces shallower and less semantically elaborate memories (Naveh-Benjamin et al., 2003). Dividing attention during encoding produced similar disruptions when learning was incidental as well. These similar impairments in memory from dividing attention when learning was either incidental or intentiona led to speculation that this disruption was affecting more than just intentional and effortful processes (Naveh-Benjamin, 2002; Naveh-Benjamin et al., 2003).

Malmberg & Shiffrin (2005) tested the effects of deep and shallow levels of processing in the mixed-pure paradigm. Results from the free recall tasks produced a null LSE supporting the REM and SAM model predictions that deeper levels of processing do not increase the amount of context storage similar to spacing repetitions (Malmberg & Shiffrin, 2005). The resultant impairment in recall from either a deep level of processing manipulation or when learning was incidental could indicate that implicit memory is affected when attention is divided during encoding.

Sahakyan & Malmberg (2018) further investigated the underlying processes of encoding while attention was divided between tasks. The experiment used distributed/spaced study as the strengthening manipulation to produce a reliable +LSE. All words were presented twice for 6s either in spaced lists (lag of 8 words before repetition) or massed lists (back-to-back) and learning occurred in either full or divided attention conditions. Two

---

4 Deep-level processing refers to a type of activity performed during encoding where ‘depth’ refers to a greater degree of semantic of cognitive analysis (Craik & Lockhart, 1972). If study emphasis focuses on meaning of a word instead of its orthography, the word is more likely to be remembered (Craik & Tulving, 1975).
experiments (one free recall, one recognition) produced expected outcomes in the full attention conditions: +LSE for free recall and a null/-LSE for recognition. However, when attention was divided during study, a different mechanism was thought to have occurred. The process to update an existing trace requires available cognitive resources to locate and retrieve it to the STS, and if dividing attention increases cognitive load on buffer, then it is likely a less taxing route will be taken, such as creating a new trace. If a new trace is created rather than updating and strengthening the original, each additional study repetition will produce a new weak trace, resulting in multiple weak traces representing study attempts of the same word. The data supported these theories by producing a null LSE in free recall, which indicates a lack of interference occurred from strong traces as well as a positive LSE was observed in recognition indicating that traces were no longer undergoing differentiation.

The effects from dividing attention during encoding showed to be more pervasive than solely reducing recall. The authors concluded that the effects of increased cognitive load during encoding impaired the subject’s ability to update an existing memory trace with new information during the second presentation of the word, and instead created a new weak trace representing the same item (Sahakyan & Malmberg, 2018). Thus, instead of a more accurate and complete trace representing a ‘strong’ word, the two study attempts are represented as two weak traces. If all traces in the set are weak, strong traces no longer have an advantage over weak during the sampling process. Additionally, if dividing attention puts strain on the buffer, it is likely that the binding process of information to traces binding will also be impaired (Lehman & Malmberg, 2013). This disruption in differentiation and interference resultant from taxing the cognitive load during encoding is an important finding for memory models. To further investigate this, six studies were conducted to determine how dividing attention affects trace accumulation, specifically contextual accumulation as well as the impact of trace interference via the LSE when IIAs are prevented from forming.

A Note on Data Analyses

The results below discuss statistical analyses for both frequentist and Bayesian ANOVAs. Each experiment was designed to collect a set sample size prior to the initiation of the experiment, and a standard significance of at least .05 was determined prior to running the frequentist ANOVAs. A brief description of the Bayesian analyses and interpretations follows. A Bayesian ANOVA contrasts the predictive performance for the data of competing models (van den Bergh et al., 2020) and penalizes more general models on their flexibility to
account for additional data patterns (such as models with additional predictors and interactions would be penalized more than more prudent models) (Rouder et al., 2016). Since Bayesian inference updates knowledge through observations/data, the Bayes Factor (BF) quantifies the relative probability of a model to describe the data against another model, which can also be interpreted as an odds ratio representing the change in belief from prior to posterior odds (van den Bergh et al., 2020). The Bayes Factor of the model \( (BF_M) \) describes the change that occurred for each model from the prior odds to posterior odds. The \( BF_{10} \) is often used to quantify the evidence in favor of the alternative hypothesis, while the \( BF_{01} \) is used to quantify evidence in favor of the null hypothesis. For example, in describing one hypothetical data set, a \( BF_{10} = 0.5 \) indicates that the data are 0.5 times more likely to occur under \( M_1 \) (‘the alternative’) than \( M_0 \) (‘the null’), while the inverse \( BF_{01} = 2 \) (or \( 1/0.5 \)) indicates the data are 2 times more likely to occur under \( M_0 \) than \( M_1 \). Common BF classifications are presented in Table 3. Typically, error rates below 20% are considered acceptable in these models (van den Bergh et al., 2020). The analysis of effects allows for us to look at the model-averaged results for a predictor from all of the models considered. The \( BF_{\text{inclusion}} \) describes the change from the prior and posterior values for a predictor (which are summed probabilities from the models that contained that particular predictor) and shows the relative evidence in the data for including that predictor (van den Bergh et al., 2020).

**Table 2. Evidence Categorization for Bayes Factor Classification**

<table>
<thead>
<tr>
<th>Bayes Factor</th>
<th>Interpretation</th>
<th>Evidence towards</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 100</td>
<td>Extreme</td>
<td>( H_1 )</td>
</tr>
<tr>
<td>30 – 100</td>
<td>Very strong</td>
<td></td>
</tr>
<tr>
<td>10 – 30</td>
<td>Strong</td>
<td></td>
</tr>
<tr>
<td>3 – 10</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>1 – 3</td>
<td>Anecdotal</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>No evidence</td>
<td></td>
</tr>
<tr>
<td>( \frac{1}{3} - 1 )</td>
<td>Anecdotal</td>
<td></td>
</tr>
<tr>
<td>( \frac{1}{3} - \frac{1}{10} )</td>
<td>Moderate</td>
<td>( H_0 )</td>
</tr>
<tr>
<td>( \frac{1}{10} - \frac{1}{30} )</td>
<td>Strong</td>
<td></td>
</tr>
<tr>
<td>( \frac{1}{30} - \frac{1}{100} )</td>
<td>Very strong</td>
<td></td>
</tr>
<tr>
<td>( \leq \frac{1}{100} )</td>
<td>Extreme</td>
<td></td>
</tr>
</tbody>
</table>

*Adapted from (Anaszewicz et al., 2015)*
Chapter Three:  

Experiment 1

As previously stated, certain methods of study form stronger traces than others. Distributing repetitions of study across a period of time allows for information to accumulate in the trace representing the repeated word, whereas massing study back-to-back will increase only item information. A full shot of context can be stored in a trace of word that is studied between 1 to 2 seconds, however, increases in study time beyond 2 s will only increase item information (Malmberg & Shiffrin, 2005). Since the working memory buffer binds both item and contextual information to the trace, this process is then contingent on how much of this limited-capacity buffer is utilized. If additional cognitive load is induced on the buffer by completing extra tasks during study, Sahakyan and Malmberg (2018) showed a disruption in the encoding process of both binding information as well as updating the traces (Sahakyan & Malmberg, 2018). If the binding process is disrupted by dividing attention, interitem associations should also be affected by the reduction in efficacy of the buffer. Therefore, degradation in forming item-to-item information would be apparent in recall by inhibiting use of a compound cue that forms after a word is recalled; the subsequent cue used to sample memory now contains the original cue plus the interitem associations (IIA) bound to the just retrieved trace (Raaijmakers & Shiffrin, 1980; Lehman & Malmberg, 2013). Experiment 1 manipulated how context accumulates in a trace, how much item information can be stored, and the effects that dividing attention will have on these traces. Dividing attention during study should disrupt the binding of both context-to-item and item-to-item information to the trace during encoding (and subsequently affecting later retrieval). Additionally, specific disruption of contextual accumulation in the trace should result in reduced overall recall with pronounced effects in spaced study compared to massed (Troyer & Craik, 2000; Malmberg & Shiffrin, 2005). Initial context stored will also be assessed by measuring First Recall Probabilities (FRP), which reflects the probability of the first word retrieved during recall. In the full attention conditions, the first word studied in delayed free recall should have the strongest context out of all other words on the list (Hogan, 1975; Lehman & Malmberg, 2013). If dividing attention successfully increases cognitive strain enough to reduce the buffer’s capacity to process and bind information effectively, the primacy effect is expected to be diminished. Contextual storage is predicted to be disrupted in both
massed and spaced lists, with a pronounced effect in spaced lists. Additionally, if dividing attention also disrupts IIAs, the asymmetry typically observed in conditional recall probability curves (CRP, discussed in detail in results) (Kahana, 1996) will also be diminished.

**Experiment 1 Methods**

**Participants**

Seventy-two USF psychology undergraduates were recruited and received course credit for their participation.

**Design**

The experiment was run in two separate parts, one with longer study times, referred to as Long Study (LS) and Short Study (SS) with shorter study times. The LS version presented weak words for 2 s and strong for 6 s, while SS version presented weak words for 1 s and strong for 3 s. The main overall design for both included Study Time (strong vs. weak) x Repetition (massed vs. spaced) x Attention (full vs. divided) mixed factorial design. Thirty-five subjects were randomly assigned to the LS experiment and 37 subjects were randomly assigned to the SS experiment. A visual representation of the presentation durations for both long and short study can be viewed in Table 3.

**Table 3.** Experiment 1 Design

<table>
<thead>
<tr>
<th>Long Study</th>
<th>Spaced</th>
<th>Massed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 distributed study attempts: 10-word lag</td>
<td>3 back-to-back study attempts</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spaced</th>
<th>Massed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short 2 s, Strong 6 s</td>
<td>Short 2 s, Strong 6 s</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Divided Attention</td>
<td>Spaced</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Short 2 s, Strong 6 s</td>
<td>Short 2 s, Strong 6 s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Short Study</th>
<th>Spaced</th>
<th>Massed</th>
<th>Divided Attention</th>
<th>Spaced</th>
<th>Massed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 s, Strong 3 s</td>
<td>1 s, Strong 3 s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 s, Strong 1 s</td>
<td>3 s, Strong 1 s</td>
<td>1 s, Strong 3 s</td>
<td>1 s, Strong 3 s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Materials

The experiment was written and administered using MATLAB and utilized the Psychophysics Toolbox extension (Brainard, 1997) software. All participants were tested in individual rooms on desktop computers and were guided through a brief practice trial prior to the start of the experiment. There were eight 20-word list variations for each participant. Lists were made by randomly sampling words without replacement from a master list of 1154 high-frequency English words (> 19 occurrences per million; Kucera & Francis, 1967). All words were presented three times in white text on a black screen, with an interstimulus-interval of 100 ms. In spaced lists, words had a lag of 10 words repeated in the same order (e.g., 1-10, 1-10, 1-10) whereas massed lists repeated words three times in a row in succession (e.g., 1, 1, 1, 2, 2, 2, etc.). The order of the different list variations were randomized for each subject.

Procedure

Practice Trial. Practice trial instructions included a description of the listening task, instruction to memorize the presented words, and instruction to attend to both the visual (words) and auditory stimuli. After an abbreviated word list, participants were told to complete simple arithmetic presented on the screen. Once 15 s elapsed (participants were not informed of time restrictions, just instructed to solve as many problems as they were able), a new screen appeared asking them to remember as many words from the recently studied list as they could. After any clarification questions had been answered, the researcher exited the room, and the participant began the experiment.

Experiment. Upon the beginning of each list, participants were shown the same instructions from the practice trial. Immediately upon conclusion of the word list (and listening task when relevant), participants completed a simple addition/subtraction distractor task for 30 seconds. Participants were then given the opportunity to recall words for 90 seconds (they were not informed of time restraints). This process repeated for the 8 list variations. The LS experiment took roughly 60 minutes, while SS experiment took only 30 minutes.

Divided Attention Task. Four of the 8 lists were Divided Attention (DA) conditions. In these conditions, participants wore headphones and tasked to monitor a sequence of digits during study of the word list. A random sequence of single digits was spoken with a female voice at a rate of 2 seconds per digit. Participants were to press a key as soon as a pattern of three odd digits was heard.
Experiment 1 Results & Discussion

Correct Recall: Long Study

Table 4. Long Study Correct Recall

<table>
<thead>
<tr>
<th>Presentation</th>
<th>Time</th>
<th>Attention</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full</td>
<td>Divided</td>
<td>Mean</td>
<td>SEM</td>
</tr>
<tr>
<td>Massed</td>
<td>6</td>
<td>0.41</td>
<td>0.03</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.31</td>
<td>0.03</td>
<td>0.19</td>
</tr>
<tr>
<td>Spaced</td>
<td>6</td>
<td>0.45</td>
<td>0.04</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.42</td>
<td>0.03</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Note: Proportion of words correctly recalled from each list type with SEM.

Figure 4. Exp 1 Long Study Correct Recall

Note: A) LS Full Attention proportion recalled as a function of presentation and study time. B) LS Divided Attention proportion recalled as a function of repetition and study time.

The proportion of correctly recalled words from LS are presented in Table 4 and Figure 4. A repeated-measures ANOVA and a Bayesian repeated-measures ANOVA was conducted for the analysis of correct recall. The repeated-measures analysis revealed main effects from Attention \( F(1,34) = 54.32, p < .001, \eta^2_p = .62 \), Repetition \( F(1,34) = 41.47, p < .001, \eta_p = .55 \), and Study Time \( F(1,34) = 34.86, p < .001, \eta^2_p = .51 \). Post hoc testing also produced significant differences for all main effects. In addition, the best fitted model generated from Bayesian ANOVA included Attention + Repetition + Study Time with a BF_M of 18.714 and a BF_10 of 6.69e^{21} (% error = 12.72) indicating the change in probability from prior to posterior and the probability of the model against the null, respectively. Analysis of effects of the BF inclusion revealed the predictors with the largest influences in the model to be Attention (BF_inclusion: 2.3e^{14}), followed by Study Time (BF_inclusion: 1.66e^{5}), and Repetition (BF_inclusion: 7.08e^{5}).
As expected, recall from the FA condition (Figure 4A) was better than in the DA condition (Figure 4B). Repetition (spaced or massed) made a difference in overall recall with spaced study resulting in higher recall probabilities for FA and DA. In LS FA, an increase in study time appeared to make more of an impact on subsequent recall when word repetition was massed during study (2 s: .31 to 6 s: .41) than when spaced (2 s: .42 to 6 s: .45), indicated that an increase in study time greatly affected item information storage in massed lists. Within the DA conditions, correct recall was reduced for both repetition types compared to the FA conditions with an increase in study time affecting recall in both spaced and massed lists somewhat equally.

**Correct Recall: Short Study**

**Table 5.** Short Study Correct

<table>
<thead>
<tr>
<th>Presentation</th>
<th>Time</th>
<th>Attention</th>
<th>Full Mean</th>
<th>Full SEM</th>
<th>Divided Mean</th>
<th>Divided SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massed</td>
<td>3</td>
<td>Full</td>
<td>0.38</td>
<td>0.03</td>
<td>0.27</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Divided</td>
<td>0.27</td>
<td>0.02</td>
<td>0.19</td>
<td>0.02</td>
</tr>
<tr>
<td>Spaced</td>
<td>3</td>
<td>Full</td>
<td>0.49</td>
<td>0.03</td>
<td>0.28</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Divided</td>
<td>0.36</td>
<td>0.02</td>
<td>0.23</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Note: Proportion of words correctly recalled from each list type with SEM.

**Figure 5.** Exp 1 Short Study Correct Recall

Note: A) SS Full Attention proportion recalled as a function of presentation and study time. B) SS Divided Attention proportion recalled as a function of repetition and study time.

Table 5 and Figure 5 show the probability of correct recall from the Short Study experiment. The most credible model produced from a 2x2x2 (Repetition x Study Time x Attention) Bayesian repeated-measures ANOVA was Repetition + Study Time + Attention + Repetition*Attention with a BF\(_M\) of 24.69 and a BF\(_{10}\) of 1.99e\(^{13}\) (error = 9.04 %). Specific large BF inclusion effects came from Study Time (BF\(_{\text{inclusion}}\): 2.61e\(^{5}\)) and Attention (BF\(_{\text{inclusion}}\): 5.06e\(^{7}\)). In addition, the 2x2x2 repeated-measures ANOVA revealed main effects from Repetition F(1,36) = 9.56,
Full attention (Figure 5A) spaced lists produced higher means in both the 1 s (.36) and 3 s (.49) than in massed lists 1 s and 3 s (.27, .38, respectively). The recall differences in the DA condition (Figure 5B) were reduced and repetition (massed vs. spaced) had less of an effect on correct recall. Although the longer study time of 3 s did improve recall, the difference in the effect between study time as well as between repetition (massed vs. spaced lists) in DA was less pronounced than it’s FA counterpart (Figure 5A) or in either LS Attention condition (Figure 4). As shown in Figure 5, repetition appeared to make matter more in the full attention condition with recall consistently higher in spaced lists. When attention was divided, the benefit to spacing repetition diminished. However, recall still improved as study time increased for both attention conditions (Figure 5), although this effect was smaller in DA. Important differences between the Long and Short Study experiments showed that the effect that spacing had on recall was present in all except SS DA. Interpretations will be addressed in the discussion.

**Serial Position: Long Study**

Serial position curves plot the probability of recall data as a function of serial position from the studied list (Murdock, 1962). Figure 6 shows the serial position curves for the full and divided attention lists across conditions (Figure 6A-D, top) with the same data binned into 3 sections (Figure 6A-D, bottom) to emphasize overall trends. Massed lists for both 6 s (Figure 6A) and 2 s (Figure 6B) indicate the presence of a primacy effect seen by the strong negative slope from the first towards middle positions in both FA and DA conditions. This tendency to recall words studied earlier in massed lists aligns with the findings from the Buffer Model (Lehman & Malmberg, 2013), where the first word on a study list enters an empty buffer and receives undivided cognitive resources to bind item and contextual information. When additional words are added to the buffer during study, resources are divided amongst the present words. Thus, stronger/better binding of contextual information will occur early in study of the list. Since massed study does not present the opportunity for multiple attempts of contextual binding (Malmberg & Shiffrin, 2005), later words on the list will have more weakly bound contextual information than earlier words.

In contrast, a flatter curve is seen in both 6 s spaced (Figure 6C, bottom) and 2 s spaced (Figure 6D, bottom) in both the FA and DA conditions. This flatter trend indicates recall was relatively stable cross all positions
in comparison to massed items. The subjects’ tendency to have higher recall probabilities across positions of a spaced lists indicates contextual and item storage was more complete or accurate, which facilitates later retrieval of these items during free recall. In addition, dividing attention decreased the probability of recall, but emulated trends in the FA counterpart for both massed and spaced repetition, suggesting that item information storage was still successful.

A 2x2x2x20 (Serial Position, SP) repeated-measures ANOVA and Bayesian repeated-measures ANOVA were used to analyze the serial position curves. The Mauchly’s test of sphericity was violated for the SP condition only, therefore corrected Greenhouse-Geisser calculations are reported for significant results including SP. The repeated-measures ANOVA revealed main effects of Attention $F(1,34)= 50.12, p<.001, \eta^2_p = .60$, Repetition $F(1,34) = 44.95, p<.001, \eta^2_p = .60$, Study Time $F(1,34)=40.03, p<.001, \eta^2_p = .54$, and SP $F(9.15, 311) = 7.99, p<.001, \eta^2_p = .19$. In addition, there were significant interaction effects for Repetition*SP $F(10.17, 646) = 4.57, p<.001, \eta^2_p = .12$ and Attention*SP $F(11.34, 385.40) = 2.48, p=.005, \eta^2_p = .07$. Post hoc tests revealed significant differences between Repetition, Study Time, Attention, and SP. The Bayesian RM ANOVA analysis produced very strong evidence for the model: Repetition + Study Time + Attention + SP + Repetition*SP with a BF$_M$ of 145.73 and a BF$_{10} = 3.64e^{65}$ (% error = 5.47).

Figure 6. Exp 1 Long Study Serial Position
Note: A) 6 s Massed. B) 2 s Massed. C) 6 s Spaced. D) 2 s Spaced.
X-axis positions correspond to the respective position of a new word when first encountered for each list. Each list has 20 unique words.
Serial Position: Short Study

Serial position data for the Short Study experiment are displayed in Figure 7. A primacy effect is present in both FA and DA for the 3 s massed condition (Figure 7A & 7C). The primacy effect observed in the SS experiment were less apparent than those seen in LS, and the study time of 1 s per presentation in massed lists did not produce this effect. SS 3 s spaced lists (Figure 7C) showed better recall of words across positions while this trend is less prominent in the 1 s per word condition (Figure 7D). Recall was diminished in both 1 s conditions indicating that study time was not long enough for sufficient contextual accumulation to occur (Malmberg & Shiffrin, 2005). Additionally, the DA conditions show a general negative shift in probable recall across positions but generally follow similar trends to the FA counterparts, suggesting item encoding was still occurring.

The strongest model produced from the Bayesian repeated-measures ANOVA for the Short Study experiment in serial recall included Attention + Repetition + Study Time + SP + Repetition*Attention (BF_M of 179.43 and a BF_{10} = 4.72e61, % error = 4.36). Similar trends were produced from the repeated-measures ANOVA showing main effects for Attention $F(1,36) = 58.90, p<.001, \eta^2_p = .62$, Repetition $F(1,36) = 29.39, p<.001, \eta^2_p = .45$, Study Time $F(1,36) = 38.68, p<.001, \eta^2_p = .52$, SP $F(19,684) = 8.29, p<.001, \eta^2_p = .19$, and Repetition*Attention $F(1,36) = 12.99, p<.001, \eta^2_p = .27$. Greenhouse-Geisser calculations are reported for analyses including SP due to a violation of sphericity in the Mauchly’s test.

**Figure 7.** Exp 1 Short Study Serial Position  
*Note: A) 3 s Massed. B) 1 s Massed. C) 3 s Spaced. D) 1 s Spaced.  
X-axis positions correspond to the respective position of a new word when first encountered for each list. Each list has 20 unique words.*
Spaced lists in both LS and SS experiments consistently exhibited larger probabilities of recall across list positions as well as in full attention conditions in comparison to lists that were massed when studied. This was expected if distributing study allows for additional attempts of context encoding, where longer study times allow for accumulation of item information and context is fully encoded when study occurs for longer than 1 s. Recall in the DA conditions were consistently lower than their respective FA conditions but maintained the same patterns indicating that the disruption in encoding emerged as an additive effect.

**First Recall Probability: Long Study**

The position of the first word recalled in the LS experiment are shown in Figure 8. Greater first recall probabilities (FRP) probabilities occurred in the FA conditions for massed and spaced repetition and diminished FRPs occurred in their DA counterparts. Differences between FA and DA FRPs were pronounced throughout the conditions with the exception of the spaced 2 s condition. A 2x2x2x20 (Attention x Repetition x Study Time x FRP) repeated-measures ANOVA and Bayesian ANOVA were conducted for FRPs. Main effects emerged for both Attention $F(1,34) = 12.68, p=.001, \eta^2_p = .28$ and Repetition $F(1,34) = 8.85, p=.005, \eta^2_p = .21$. The most credible model produced from the Bayesian ANOVA was also Attention + Repetition with a $BF_m$ of 25.19 and a $BF_{10}$ of 294.10, (% error = 2.30). Analysis of effects revealed the most impact from the predictors: Attention ($BF_{inclusion}: 19.60$) and Repetition ($BF_{inclusion}: 3.90$).

The observed primacy effects shows that subjects had the greatest tendency to recall words that were studied initially indicating these words had the strongest and most accurate context bound to their trace. Although present in both repetition conditions, this primacy effect is most evident in massed study. Dividing attention disrupted the observed primacy effect across conditions in LS.

**First Recall Probability: Short Study**

First recall probabilities for the Short Study experiment are shown in Figure 9. A 2x2x2x20 Attention x Repetition x Study Time x FRP Bayesian ANOVA included only Attention (BF$_{M}$ of 17.58 and a BF$_{10}$ = 16.44, % error = 1.52) as the most credible model. The 2x2x2 repeated-measures ANOVA produced Attention as a significant main effect $F(1,36) = 14.02, p<.001, \eta^2_p = .28$, along with an interaction of Repetition*Study Time
$F(1,36) = 4.78, p < .05, \eta^2_p = .12$. Larger probabilities of first recall for position 1 were observed in the FA conditions than in the DA conditions (with the exception of 1 s massed showing a minimal difference).

Although probabilities were not as large as observed in the LS experiment, subjects still tended to show FRPs from the primary positions in each list variation. The smallest difference between FA and DA was observed in the 1 s massed condition (Figure 9 top left), were both FA and DA had similar probabilities of first recall. In this condition, it is likely that study time was too brief to fully store accurate contextual information. With little study time and possibly only one attempt to copy context information, retrieval of these quickly constructed traces would be difficult.

![Figure 8](image_url)  
**Figure 8.** Exp 1 Long Study First Recall Probabilities  
*Note: Top Left: 2 s Massed. Top Right: 2 s Spaced. Bottom Left: 6 s Massed. Bottom Right: 6 s Spaced. X-axis positions correspond to the respective position of a newly studied word when first encountered in each list. Each list has 20 unique words.*

![Figure 9](image_url)  
**Figure 9.** Exp 1 Short Study First Recall Probability  
*Note: Top Left: 1 s Massed. Top Right: 1 s Spaced. Bottom Left: 3 s Massed. Bottom Right: 3 s Spaced. X-axis positions correspond to the respective position of a newly studied word when first encountered in each list. Each list has 20 unique words.*
Conditional Recall Probability: Long Study

In order to assess the degree of potentially shared contextual information and interitem associations between items, conditional recall probability (CRP) curves were plotted. These curves represent the sequential contingencies in recall order from participants and show the likelihood of recalling a certain item y immediately after recalling item x, also known as lag. The absolute value of lag is a measure of remoteness of a correctly recalled item from the initial input order. A positive lag is indicative of recall in a forward order, while a negative lag is recalling items previous to that item in input order (Kahana, 1996). A typical CRP curve is asymmetrical, with a shallow slope for negative lag and a strong negative slope in the positive lag direction.

![CRP Curves](image)

**Figure 10.** Exp 1 Long Study Conditional Recall Probabilities
*Note: Top Left: 2 s Massed. Top Right: 2 s Spaced. Bottom Left: 6 s Massed. Bottom Right: 6 s Spaced.*

As is shown in Figure 10, the FA conditions (solid lines) show a trend of a shallow positive slope from the negative positions towards lag 0, and then a sharp negative slope past lag 0 in the positive lag direction. When attention was divided, the tendency to recall the next subsequent word on a list was often drastically diminished. Bayesian paired-samples t-tests revealed many strong differences between lag positions 1 and 2 in the FA conditions but not the DA counterparts, giving further indication of a shallower slope in the divided attention conditions. Six seconds massed study showed strong evidence for the difference in CRP for lag position 1 and 2 in FA (BF$_{10}$ of 1599.27, error = 7.03e$^{-7}$ %), which was reduced in the DA condition to a BF$_{10}$ of 39.41 (% error = 1.19e$^{-7}$ %).

Although not as robust, there was evidence for differences in 2 s massed FA (BF$_{10}$ of 97.29, error = 7.15e$^{-8}$ %) and DA (BF$_{10}$ of 1.76, error = 9.26e$^{-5}$ %). Spaced study comparisons revealed strong evidence for differences in lag positions 1 and 2 for the 6 s condition for FA (BF$_{10}$ of 3613.68, error = 2.14e$^{-6}$ %) and DA (BF$_{10}$ of 3.92, error = 0.002 %) as well as 2 s in the FA (BF$_{10}$ of 40.02, error = 1.17e$^{-7}$ %) and DA (BF$_{10}$ of 2.98, error = 0.002 %).
conditions. These strong differences in BF₁₀’s further support that the DA conditions were shallower than the FA counterpart.

The asymmetrical slopes with a negative slope in the positive lag positions were observed for all FA conditions indicating that subjects were successfully storing IIAs during study and this information was utilized during the free recall process. As study time increases, this additional duration could be devoted to binding item information, which would likely result in larger negative slopes (Figure 10 bottom row). Results from the DA conditions produced CRP curves with shallower negative slopes revealing that use of IIA was diminished, which would be likely resultant of impaired encoding/strengthening of this information. If dividing attention disrupts trace accumulation (Sahakyan & Malmberg, 2018), then these shallower slopes are expected if IIA information is incomplete and/or error prone preventing retrieval connections between studied words which is revealed through forward.

CRPs were also analyzed as a 2x2x2x8 Attention x Repetition x Study Time x Lag using frequentist and Bayesian repeated-measures ANVOA. Main effects were seen for Attention $F(1,34) = 48.92, p < .001, \eta^2_p = .19$, Lag $F(1.53, 51.99) = 45.12, p < .001, \eta^2_p = .57$, Study Time $F(1,34) = 25.33, p < .001, \eta^2_p = .11$, and Repetition $F(1,34) = 14.66, p < .001, \eta^2_p = .30$. In addition, interactions were observed between Study Time*Lag $F(3.91, 132.90) = 4.37, p < .005, \eta^2_p = .11$ and between Attention*Lag $F(2.39, 81.09) = 7.17, p < .001, \eta^2_p = .17$. Post hoc testing revealed strong significant differences between all main effects. The Bayesian analysis tested a total of 167 models and the most credible produced included three main effects and two interactions: Attention + Study Time + Lag + Study Time*Attention + Attention*Lag, with a BF₉ of 133.65 and a BF₁₀ of 3.78e¹²⁷ (error = 1.75 %). The analysis of effects gave support for this model with the strongest influences from the predictors: Attention (BF inclusion: 6.87e⁷), Lag (BF inclusion: 1.16e¹⁵), and Attention*lag (BF inclusion: 4.99e⁵).

**Conditional Recall Probability: Short Study**

Short study CRPs (Figure 11) were analyzed in the same method as described in LS. Bayesian paired-samples t-tests were used to assess potential differences between Lag +1 and +2 across the conditions. Positive lag positions for the FA conditions (solid lines) typically showed a more pronounced negative slope in comparison to the negative lag, with the exception of the 1 s massed condition. There was little evidence for a difference between positions +1 and +2 for these shallow slopes seen in the 1 s massed positive lag for FA (BF₁₀ of 0.74, error = 1.47e⁷
%) or DA (BF\textsubscript{10} of 28.26, error = 1.08\texttimes10^{-7}%). Additionally, there also was little evidence for a difference between DA lag +1 and FA lag +1 (BF\textsubscript{10} of 0.27, error = 2.05\texttimes10^{-6}%).

When items were studied in the shorter conditions (1 s and 3 s), an unexpected steeper slope emerged in the DA positive lag than in the FA positive lag in three out of the four conditions. Additionally, there was stronger evidence for a difference in the positive lag 1 and 2 position for DA 3 s spaced (Figure 11 bottom right) (BF\textsubscript{10} of 55.08, error = 5.95\texttimes10^{-8}%), FA 3 s spaced lag +1 and +2 (BF\textsubscript{10} of 9.10, error = 6.15\texttimes10^{-4}%), DA 3 s massed (Figure 11 bottom left) (BF\textsubscript{10} of 26.73, error = 1.14\texttimes10^{-7}%), and 3 s massed FA (BF\textsubscript{10} of 13.84, error = 7.11\texttimes10^{-4}%) which gives further evidence for the visually steep slopes.

A 2x2x2x8 (Attention x Repetition x Study Time x Lag) repeated-measures ANOVA and Bayesian ANOVA were also used to assess Short Study CRP. The most credible model produced from the Bayesian ANOVA included three main effects and an interaction: Attention + Study Time + Lag + Study Time\texttimes Lag with a very strong BF\textsubscript{M} of 933.73 and a BF\textsubscript{10} of 1.60\texttimes10^{70} (error = 1.68%). Notable Bayesian post hoc differences included attention, study time, and lag. The ANOVA produced three main effects of interest: Attention $F(1,36) = 30.53$, $p < .001$, $\eta^2_p = .46$, Lag $F(3.04,109.48) = 41.03$, $p < .001$, $\eta^2_p = .53$, Study Time $F(1,36) = 22.38$, $p < .001$, $\eta^2_p = .38$, with one interaction, Study Time\texttimes Lag $F(3.15,113.25) = 3.75$, $p < .05$, $\eta^2_p = .09$. Post hoc analyses revealed significant differences in Attention, Repetition, and Study Time.

In the longer study times for the FA conditions (3 s massed and spaced, Figure 11 bottom row), asymmetry was more apparent than when words were studied for only 1 s. When study occurs for only 1 s at a time, the shallow slope indicates the buffer had little time for attempts to store information, thus little item information was stored (including incomplete context), resulting in less distinct differences between full and divided attention.
conditions. Small differences between recall from words studied for a brief 1 s per presentation under full or divided conditions shows that 1 s of study is an insufficient amount of time for full context storage (Malmberg & Shiffrin, 2005) even when cognitive resources are strained and subsequently disrupting IIA storage (Lehman & Malmberg, 2013).

**Experiment 1 Conclusions**

Within the first 1 to 2 seconds of study, an attempt to store contextual information occurs. Increases in study duration past two seconds consistently shows to not strengthen context storage but rather is attributed to binding item information. Whereas distributed study allows for multiple attempts to store context resulting in accumulation, massing study does not (Malmberg & Shiffrin, 2005). Sahakyan & Malmberg (2018) found evidence that dividing attention during study disrupted item and context storage and accumulation.

Experiment 1 investigated the effects of divided attention on contextual accumulation and possible disruption item-item information binding. Items presented in both the LS and SS experiments existed in pure lists (all words on a list were equal in study time and number of study attempts) yet recall of FA words were consistently higher for spaced rather than massed lists. Distributing study allowed for accumulation contextual information in the traces shown by increases in recall across the list positions. These increases in contextual storage should have led to successful sampling and recovery process as the test cue probing memory should share more similarities to these accurately stored traces (Raaijmakers & Shiffrin, 1980).

Increases in study time led to increases in recall for both spaced and massed lists, indicating that more complete or accurate traces were formed when study time was extended. Study times of at least 2 s appeared to be long enough to completely store context as seen in the serial position curves (Figure 6,7) as well as in the CRP forward lags (Figure 10,11). However, when items were presented for study for 1 s, the duration produced curves supporting evidence of partially contextual storage. 1 s massed study produced a symmetrical CRP curve (Figure 11 top left) and a greatly reduced FRP (Figure 9 top left) whereas spacing study for 1 s produced small, but present evidence.

The CRP graphs typically showed the largest probability for recall at the +1 lag position, indicating that the most probable word to recall next was the word subsequently studied (e.g., if the word studied at position 6 was just output, then the next word to be output would be word 7). However, when attention was divided during study, the
pattern of forward CRP often was diminished, describing a reduced use of contextual and IIA information during free recall.

Dividing attention reduced recall for both LS and SS. The increase in strain on the buffer resulted in fewer resources devoted to binding information to the traces of studied items. In Short Study, dividing attention showed greater decreases in recall for spaced (e.g., 3 s spaced .49 FA – .28 DA = .21) than in massed conditions (e.g., 3 s massed .38 FA - .27 DA = .11). When examining correct recall between LS and SS, massed lists from both LS and SS DA conditions resulted in almost identical correct recall means. However, correct recall for spaced words showed a larger drop in recall in SS, which may indicate that any disruption that occurs in traces during shorter study times affects storage more drastically than longer study times. Even in longer study times, dividing attention still impacted later recall, yet shorter study times appeared to be affected differently. Shorter durations of study decrease the amount of information that are able to be extracted from the current study item and adding additional strain (by dividing attention) on an already brief study duration might cause the participant to miss storing the presented word. Less information bound or missed storage attempts would lead to weaker traces and could explain the SS DA correct recall results.

Overall, Experiment 1 supports the hypothesis that dividing attention during study disrupts accumulation and storage of context and item information. Although recall of words was reduced in the DA conditions, the pattern observed in the FA condition was often maintained in the DA counterpart indicating a more subtle disruption in encoding and/or accessibility to contextual and interitem information. The effect of disruption in the accumulation of contextual information was most pronounced when study was spaced. In conditions where words studied were given enough time to effectively encode a full shot of context (e.g., 6 s, 3 s, 2 s), recall patterns were observed to show successful use of stored contextual information during recall (as shown by FRP and CRP graphs, Figures 8 – 11). However, induced strain on cognitive resources available to the buffer consistently showed large reductions in later recall.

Additionally, massed lists showed larger primacy effects than spaced lists. When the buffer handles only a single word, cognitive resources are devoted to binding information to this item. As the next word enters the buffer, resources are then divided among extant words to efficiently handle multiple items (Lehman & Malmberg, 2013). Since each word in a massed list receives only one attempt to store context, the first word in a list should have the most thorough binding of contextual information. Subsequent words will always occupy the buffer with another and
thus not receive the same resources as the first word. Since stronger (more information and accurate) traces are more likely to be sampled from matching features with a contextual cue, these differences in contextual information between earlier and later words are shown by the primacy effects observed in massed lists in Figures 6 through 9. In contrast, spaced list words should receive multiple chances to store context providing a stronger more evenly spread of strong contextual cues across words.

Experiment 1 was effective in showing how dividing attention disrupts specific components of a trace, but this disruption is not equivalent across massed and spaced study. Item information appears to be maintained but reduced, while item-context and item-item information is affected more greatly when words are spaced or studied for brief amounts of time. The following experiment tests findings from Malmberg & Shiffrin (2005) and Sahakyan & Malmberg (2018) through investigating the effects of divided attention when words are strengthened by study time in a mixed-pure list paradigm.
Chapter Four:

Experiment 2

Sampling of a trace during the retrieval process is not only dependent on the trace, but also the other traces in the search set (Atkinson & Shiffrin, 1968, Raaijmakers & Shiffrin, 1980, Shiffrin & Steyvers, 1997). The +LSE, or the memory for weak words on pure lists are remembered better than weak words on mixed lists, is typically observed in free recall and explained by interference from strong words in the sampling of weak words. Results from Sahakyan and Malmberg (2018) showed novel evidence that dividing attention during study produced a null LSE in later recall. A lack of interference from strong words was hypothesized to explain the null LSE, which may have been from a lack of strengthening in traces. The positive LSE obtained in recognition in the divided attention condition further supported their interpretation by demonstrating that differentiation between traces did not occur.

In theory, since stronger traces have increased item and contextual information, these traces should be sampled at a higher rate than weaker traces in free recall. However, if dividing attention disrupts this accumulation of information, strong words in a mixed-pure design should be more affected than the weak words.

The second experiment in Malmberg and Shiffrin (2005) found an importance in time that it takes for a full shot of context to be stored. When items were strengthened for 1 s per presentation, a null LSE was produced, but increasing study to 2 s per word produced a +LSE indicating that context was unable to fully store at 1 s. This discrepancy in time led to further testing indicating that in order to have a full shot of context, study needs to occur between 1 and 2 second. However, if attentional demands are required for successful binding of information to the trace (Sahakyan et al., 2014; Sahakyan & Malmberg, 2018), context encoding should require attentional demand to fully bind information and accumulate.

The current study used a mixed-pure design, with words strengthened by time, with each word presentation displaying weak words for 1 s and strong words for 3 s. All words were repeated three times in a distributed order to allow for multiple attempts to strengthen and store contextual information. Attention was manipulated within subjects, with lists studied in both full and divided attention conditions. Lastly, order of presentation for strong items was manipulated between subjects. If dividing attention induces cognitive strain on the buffer, the subject’s
ability to bind information as well as updating traces on subsequent study attempt will result in multiple weak traces representing a word studied multiple times. If study order is not repeated, item-item information should vary as repetition of study occurs. Since interitem associations (IIA) are thought to contribute to the +LSE (Malmberg & Shiffrin, 2005), differing the order of study should prevent IIA strengthening and reducing the effect.

Experiment 2 Methods

Participants

Eighty USF psychology undergraduates were recruited through Sona and received course credit for their participation.

Design

This experimental design was a 2x2x2x2 mixed design. The only between-subjects condition was Order (same vs. different order), and within-subjects conditions included Attention (full vs. divided) x Strength (strong, 3 s vs. weak, 1 s) x List Type (pure vs. mixed). Words presented in the same order (SO) condition were repeated in the same order, i.e. 1-10, 1-10, 1-10, while words in the different order (DO) condition were presented in the following order: 1-10; 3, 8, 2, 5, 1, 7, 10, 6, 9, 4; and 3, 1, 10, 2, 9, 5, 8, 6, 4, 7. All repeated items in the SO condition had a lag of nine words before the word was studied again. There were eight list types within the SO condition and eight list types within the DO condition. All words were studied three times and shown in white text for a duration of 1 or 3 s for each presentation on a black screen. Thus, total study time for words was either 3 s or 9 s. The 4 list types that were studied in full attention and divided attention: pure weak (PW), pure strong (PS), mixed31 (ML31), mixed13 (ML13). A PW list consisted of words presented three times for 1 s, while a PS list consisted of words presented three times for 3 s each. Mixed Lists contained 10 weak (3 x 1 s) and 10 strong (3 x 3 s) words and were blocked by strength. A mixed31 list presented the 10 strong words before the 10 weak words, while a mixed13 list presented the 10 weak words before the 10 strong words. A summary of the Experiment 2 list design is displayed below in Table 6.
Table 6. Experiment 2 Design

<table>
<thead>
<tr>
<th>Design</th>
<th>List Type</th>
<th># Presentations x Study Duration</th>
<th># Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>Pure Weak</td>
<td>3 x 1 s</td>
<td>20</td>
</tr>
<tr>
<td>DA</td>
<td>Pure Strong</td>
<td>3 x 3 s</td>
<td>20</td>
</tr>
<tr>
<td>PW</td>
<td>Mixed</td>
<td>weak 3 x 1 s</td>
<td>10</td>
</tr>
<tr>
<td>PW</td>
<td>PS</td>
<td>strong 3 x 3 s</td>
<td>10</td>
</tr>
<tr>
<td>PW</td>
<td>ML13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PW</td>
<td>ML31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PW</td>
<td>ML31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PW</td>
<td>ML31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PW</td>
<td>ML31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PW</td>
<td>ML31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PW</td>
<td>ML31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PW</td>
<td>ML31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PW</td>
<td>ML31</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Materials

The experiment was written and administered using MATLAB and the Psychophysics Toolbox extension (Brainard, 1997) software. There were 16 list variations in total for each participant. Each 20-item list was created by randomly sampling words without replacement from a list of 1154 high frequency English words (>19 occurrences per million; Kucera & Francis, 1967). Strong words were spaced and had a lag of 10 words for every presentation (e.g., 1-10, 1-10, 1-10). The Order condition (same vs. different) was blocked so that all eight SO lists (or eight DO lists) were encoded together. Presentation order of the list variations were randomized for each subject. Participants were provided with standard over the ear headphones but were allowed to use their own if preferred.

Procedure

All participants were tested in individual rooms on desktop computers. After obtaining consent, participants were guided through a brief practice trial by the experimenter to orient them to the main experimental procedures.

Practice Trial. Practice trial instructions included a description of the listening task, instruction to memorize the presented words, and instruction to attend to both the visual (words) and auditory stimuli. After an abbreviated word list, participants were told to complete simple arithmetic presented on the screen. Once 15 s elapsed (participants were not informed of time restrictions, just instructed to solve as many problems as they were able), a new screen appeared asking them to remember as many words from the recently studied list as they could. After any clarification questions had been answered, the researcher exited the room, and the participant began the experiment.
**Experiment.** Upon the beginning of each list, participants were shown the same instructions from the practice trial which included instruction to memorize the following words and instructions for the listening task (when applicable). Immediately upon conclusion of the word list (and listening task when relevant), participants completed a simple addition/subtraction distractor task for 30 seconds. Once this time elapsed, participants were given the opportunity to recall as many words as they remembered from the word list for 90 seconds (they were not informed of time restraints). A black screen with prompts stating to continue when ready appeared after the 90 s elapsed. This process was repeated until all eight list variations were completed for the particular order condition was completed. A blue screen then appeared with prompts that the participant was midway through the experiment and to continue when ready. The second Order condition was then completed in the same manner as described above.

**Divided Attention Task.** In the eight Divided Attention (DA) variations, participants wearing headphones were tasked to simultaneously monitor the sequence of digits while studying the word list. A random sequence of single digits was spoken with a female voice at a rate of 2 seconds per digit (this was the frequency used in Sahakyan & Malmberg (2018)). The task was to press a key when a pattern of three odd digits was heard. All subject’s performance on the divided attention was checked before including data in analysis to ensure attention was applied to the extra task.

**Experiment 2 Results & Discussion**

**Experiment 2 Same Order Correct Recall**

The correct recall SO condition full (FA) and divided attention (DA) are shown in Table 7 and Figure 12A and 12B. As a reminder, strong words were spaced 3 times and seen for 3 s in each presentation and weak words were presented once for 1 s. The FA condition (Figure 12A) did not produce a List-Strength Effect (LSE) with minimal differences between strong words in mixed (.52) and pure (.51) lists as well as in weak words (.35, .33) for mixed and pure lists, respectively. The DA conditions, shown in Figure 12B, reduced probability of correct recall in comparison to FA. Small but nonsignificant differences emerged in the DA condition for weak words in mixed (.18) and pure (.22) lists and for strong words in mixed (.36) and pure (.33) (Figure 12B). These differences are small but shows a small but positive LSE pattern with increased recall for strong words in mixed lists and better
recall for pure weak words. A 2x2x2 (Attention x List Type x Strength) Bayesian ANOVA for the same order condition provided moderate to strong evidence for the model of Attention + Strength with a BF_{M} of 14.47 and a BF_{10} of 1.46e^{24} (error = 1.82 %). The evidence in the data for including these predictors in the model were Attention (BF_{inclusion}: 4.29e^{12}) and Strength (BF_{inclusion}: 4.60e^{14}). Further supporting these findings, a 2x2x2 (Attention x List Type x Strength) repeated-measures ANOVA had main effects in Attention F(1,39) = 72.21, p < .001, η_{p}^{2} = .65 and Strength F(1,39) = 63.89, p < .001, η_{p}^{2} = .62. Attention and Strength (time spent studying the words) were produced in both analyses and further supports these variables were affecting the probability of recall.

Table 7. Exp 2 Same Order Correct Recall

<table>
<thead>
<tr>
<th>List</th>
<th>Strength</th>
<th>Attention</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full</td>
<td>Divided</td>
</tr>
<tr>
<td>Pure</td>
<td>Mean</td>
<td>SEM</td>
</tr>
<tr>
<td>Weak</td>
<td>0.33</td>
<td>0.02</td>
</tr>
<tr>
<td>Strong</td>
<td>0.51</td>
<td>0.03</td>
</tr>
<tr>
<td>Mixed</td>
<td>Mean</td>
<td>SEM</td>
</tr>
<tr>
<td>Weak</td>
<td>0.35</td>
<td>0.03</td>
</tr>
<tr>
<td>Strong</td>
<td>0.52</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Note: Proportion of words correctly recalled from each list type with SEM.

Figure 12. Exp 2 Same Order Correct Recall

Note: A) SO Full Attention. B) SO Divided Attention.

To further determine if interactions were present in the correct recall data, separate List Type (2) x Strength (2) ANOVA for the FA condition revealed a main effect for only Strength F(1,39) = 38.40, p < .0001, η_{p}^{2} = .28, whereas a Type (2) x Strength (2) ANOVA for the DA condition produced main effects of Strength F(1,39) = 18.65, p < .0001, η_{p}^{2} = .07 and the interaction List*Strength F(1,39) = 18.65, p < .0001, η_{p}^{2} = .07. The most credible Bayesian model for the FA condition included only Strength (BF_{10} = 2.74e^{7}) whereas the DA condition model included Strength + List*Strength (BF_{10} = 458.85).
Experiment 2 Different Order. Correct Recall

The correct recall different order (DO) conditions for full and divided attention are shown in Table 8 and Figure 13A and 13B. The only difference in design from the SO condition was the order of presentation of spaced words. Each repetition of strong words occurred in a different order to prevent interitem associations (IIA) from strengthening due to repeated order (i.e., SO). DO correct recall produced null LSEs in both FA and DA conditions with correct recall reduced in the DA condition. A 2x2x2 (Attention x List Type x Strength) Bayesian ANOVA produced Attention + List Type + Strength + Attention*Strength with a BF$_M$ of 13.30 and BF$_{10}$ of 1.11e$^{23}$ (error = 5.05 %) as the best model (notable BF$_{inclusion}$ included Attention: 1.79e$^{12}$ and Strength, 1.17e$^{13}$). Additionally, a 2x2x2 (Attention x List Type x Strength) repeated-measures ANOVA showed similar results including main effects of Attention $F(1,39) = 77.60, p<.001, \eta_p^2 = .68$, List Type $F(1,39) = 8.03, p<.01, \eta_p^2 = .18$, Strength $F(1,39) = 51.24, p<.001, \eta_p^2 = .58$, and Attention*Strength $F(1,39) = 6.34, p<.01, \eta_p^2 = .15$. Additionally, a Study Order (2) x List (2) x Strength (2) mixed ANOVA was conducted intending to compare the effects of order of study in correct revealed no difference between study order ($p = 0.15$).

Table 8. Exp 2 Different Order Correct Recall

<table>
<thead>
<tr>
<th>List</th>
<th>Strength</th>
<th>Attention</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Full</td>
<td>Divided</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Mean</td>
</tr>
<tr>
<td>Pure</td>
<td>Weak</td>
<td>0.28</td>
<td>0.02</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td>0.46</td>
<td>0.03</td>
<td>0.30</td>
</tr>
<tr>
<td>Mixed</td>
<td>Weak</td>
<td>0.30</td>
<td>0.02</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td>0.47</td>
<td>0.03</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Note: Proportion of words correctly recalled from each list type with SEM.

Figure 13. Exp 2 Different Order Correct Recall

Note: A) DO Full Attention. B) DO Divided Attention.
**Experiment 2 Correct Recall Discussion**

In free recall, if there is little interference from strong words on weak words within a mixed list, a positive LSE is not expected. In Malmberg and Shiffrin (2005), the third experiment describes how this difference in effect from strong and weak words may emerge. Among the many conditions, study time of an item was manipulated in a short (1s and 3s) and long (2s and 6s) condition where words studied one time. When weak words in the short condition were presented below the estimated time for a full shot of context to occur, the short and only instance of study time allowed for only partial context could occur (Malmberg & Shiffrin, 2005). Since the sampling process in recall utilizes the context stored in traces, stronger traces (or items studied long enough to attempt a full shot of context, e.g., 3 s in the short condition) will have a sampling advantage over weak words (e.g., weak words containing only partial context storage) in mixed lists. Thus, results from Malmberg and Shiffrin (2005) in the short study condition produced a small positive LSE, indicating that one presentation was enough to produce a difference in context strength for words studied for 1 s or 3 s. However, the long study condition of 2 s and 6 s, where both study times occurred long enough for a full shot of context to occur, produced a null LSE. If the amount of context stored in weak and strong words are similar in strength, this sampling advantage effect during free recall should disappear. The number of times a word is studied also drives this difference in context stored. When words were studied for 1 s only once or three times, a strong positive LSE emerged providing evidence for a difference in context storage when manipulating number of times studied (this effect was greatly reduced when massing study with matched time). Word order repetition was also manipulated, showing a tempered +LSE in comparison to repeating order (Malmberg & Shiffrin, 2005).

In the current experiment, all words had three presentations, contextual storage would have the same number of chances to accumulate in both strong and weak words. However, the difference in study duration manipulated whether a full shot (3 s) or partial amount (1 s) of context could be stored in the trace in each attempt. This would lead to the assumption that strong words should have more accurate and stronger contextual information over the three presentations than weak words, so this null LSE was unexpected. The null LSE was also preserved when disrupting study order, showing that the effect of interitem association information in the SO FA condition was not enough to drive a +LSE.

A small positive LSE appeared in the divided attention (Figure 12B) condition. According to Sahakyan and Malmberg (2018), dividing attention during study disrupts the buffer’s ability for binding information in
addition to forming multiple traces (rather than updating the original trace) for additional study attempts, therefore it would be expected that all words in this condition would be weak traces (three separate weak traces representing strong words and three separate traces for weak) leading to null LSE. It’s possible that in the FA conditions, even though words were presented below the estimated time for a shot of context to be stored, the three spaced presentations allowed for context to accumulate in strength, whereas strong items would bind this information on the first attempt and then taper off in accumulation on subsequent attempts. The +LSE in the DA condition would be explained by the disruption of accumulation, producing a difference in stored context between weak and strong items.

**Serial Position**

Serial Position of words recalled for the same order and different order conditions are shown in Figure 14 and Figure 15 below.

![Figure 14. Exp 2 Pure Lists Serial Position](image)

**Note:** A 20-item word list was compiled into 10 bins, spanning two serial positions each. E.g., position 3 corresponds to the fifth and sixth word studied during the initial occurrence. Each x-axis position shows the average recall across those serial positions. Each list has 20 unique words.

**Experiment 2 Same Order.** Probability of recall across serial positions (binned by two positions) graphs are separated by pure (Figure 14) and mixed lists (Figure 15) with weak and strong words in the top and bottom rows, respectively. The left column in Figures 14 and 15 show results from the SO conditions. For most positions and in both list types, FA (solid line) showed better recall than DA across positions in both strong and weak words. Attention appeared to have the smallest effect in pure weak SO lists, whereas the difference in recall between attention conditions was greater from mixed weak lists. An odd sharp drop is seen for positions 7 and 8 in pure
strong lists, but the sharp change restored to previous position recall values for the remainder of the list. Recall was reduced in DA conditions and appeared more variable across list types than in FA conditions. A 2x2x2x10 (Attention x List Type x Strength x Binned Serial Position (SP)) Bayesian ANOVA was conducted. The most credible model had three effects: Attention + Strength + SP with a BF$_M$ of 1038.82 and BF$_{10}$ of 3.89e$69$ (error = 1.21 %). Among all possible predictors, the largest Bayesian inclusion factors were all present in the model (BF$_{inclusion}$: Attention = $\infty$, Strength = $\infty$, and SP = 1.11e$4$). A repeated-measures 2x2x2 (Attention x List Type x Strength x Serial Position (SP)) ANOVA produced the same main effects as in the Bayesian model: Attention $F(1,39) = 97.70$, $p<.001$, $\eta^2_p = .72$, Strength $F(1,39) = 110.73$, $p<.001$, $\eta^2_p = .74$, and SP $F(6.50, 253.51) = 6.92$, $p<.001$, $\eta^2_p = .15$.

**Figure 15.** Exp 2 Mixed Lists Serial Position

*Note: A 20-item word list was compiled into 10 bins, spanning two serial positions each. E.g., position 3 corresponds to the fifth and sixth word studied during the initial occurrence. Each x-axis position contains the average recall across those serial positions. Each list has 20 unique words.*

**Experiment 2 Different Order.** DO serial positions are also graphed in the right column of Figures 14 and 15. Although only one order is plotted in the graph, each order was checked to ensure that a specific order was not more influential in recall than others. Since little-to-no difference was found, the first presentation order of words was plotted. Negative shifts in recall occurred for DA conditions (in comparison to FA) across positions are present, while pure weak lists showed the least difference between attention conditions. The most credible model from the 2x2x2x20 (Attention x List Type x Strength x Binned Serial Position (SP)) Bayesian ANOVA was fairly complicated and included a large number of predictors: Attention + List Type + Strength + SP + Attention*List Type + Attention*Strength + List Type*Strength + Attention*SP + Attention*List Type*Strength. Although complicated, the evidence for the model by standard evaluations is still considered extreme, with a BF$_M$ of 275.27 and BF$_{10}$ of 1.33e$62$ (error = 4.81 %). The evidence for including each predictor in the models (measured by
BF\textsuperscript{inclusion} was as follows: Attention (1.38e\textsuperscript{13}), List Type (1.38e\textsuperscript{13}), Attention*List Type (2.30e\textsuperscript{10}), Strength (1.38e\textsuperscript{13}), Attention*Strength (1.06e\textsuperscript{14}), List Type*Strength (1.62e\textsuperscript{14}), List Type*Strength (71781.75), Attention*List Type*Strength (1.62e\textsuperscript{11}), and finally SP (1.9e\textsuperscript{8}). The 2x2x2 (Attention x List Type x Strength x Serial Position (SP)) repeated-measures ANOVA also had similar significant main effects of Attention \(F(1,39) = 104.80, p<.001, \eta^2_p = .73\), Strength \(F(1,39) = 25.44, p<.01, \eta^2_p = .40\), SP \(F(6.84, 266.64) = 6.05, p<.001, \eta^2_p = .13\), Attention*Strength \(F(1,39) = 28.90, p<.001, \eta^2_p = .42\), List Type*Strength \(F(1,39) = 38.64, p<.001, \eta^2_p = .50\), and Attention*List Type*Strength \(F(1,39) = 30.81, p<.001, \eta^2_p = .44\).

**Serial Position Conclusions**

Minimal differences appeared across positions in serial position between study order conditions indicating word order did not strongly contribute to trends in recall. Although divided attention reduced recall probability across positions, smaller differences between full and divided attention appear more consistent SO and DO pure weak conditions. This could be due to the attention manipulation affecting weak words less due to the attention number task occurring at a slower rate between number presentations than the word duration. In contrast, larger differences can be seen in SO DA mixed lists, showing the recall of weak words were disproportionately affected within the list.

**First Recall Probability**

First Recall Probabilities (FRP) are displayed in Figures 16 and 17 for pure and mixed lists in SO (left columns) and DO (right columns) conditions below.

**Experiment 2 Same Order FRP.** Strong words in both pure and mixed lists showed a strong primacy effect in the FA conditions. Pure weak lists showed less of an effect in primacy than mixed weak lists. Additionally, although disruptions in primacy are seen in the DA conditions for pure strong and mixed weak lists (the reduction in probability in comparison to FA), the pure weak and mixed strong lists showed similar first recall probabilities in the corresponding DA conditions.
A 2x2x2x20 (Attention x List Type x Strength x First Recall Position (FRP)) Bayesian ANOVA and repeated-measures ANOVA were conducted. Strength + FRP was the most credible model with a BF\textsubscript{M} of 178.97 and a BF\textsubscript{10} of 1.32\times10^2 (error = 1.85 %). Bayesian inclusion factors in all predictors were minimal with the extreme exception for the FRP predictor only (BF\textsubscript{inclusion} = \infty). The repeated-measures ANOVA produced similar effects in Strength $F(1,39) = 14.78, p < .001, \eta^2_p = .28$ and Position $F(7.06, 275.29) = 8.47, p < .001, \eta^2_p = .18$, with interactions between List Type*Strength $F(1,39) = 16.26, p < .001, \eta^2_p = .29$ and Attention*List Type $F(1,39) = 5.28, p < .05, \eta^2_p = .12$ were also found to be significant.

Experiment 2
Different Order FRP.

Pure lists produced stronger primacy effects than mixed lists in the DO condition. Oddly, dividing attention during study in DO pure weak conditions produced a larger primacy effect.
in the first position than in the FA condition, while any primacy effect in other DO DA conditions were reduced in comparison to FA. When comparing strong words from mixed lists, the DO condition had a distinct reduction in primacy (almost by half) than the SO condition.

The top model from the Bayesian ANOVA included only FRP with BF$_{M}$ of $1.14 \times 10^{-4}$ and a BF$_{10}$ of $5.17 \times 10^{13}$ (error = 0.24 %). In contrast, the second-best model had a drastically reduced BF$_{M}$ of 11.20 which included only FRP + Strength (BF$_{10}$ of $3.75 \times 10^{12}$, error = 4.26 %). The BF inclusion for FRP was $6.92 \times 10^{12}$ and Strength was 0.009, providing further evidence that the best model included only one variable. The repeated-measures ANOVA produced main effects of Attention $F(1,39) = 6.56, p<.05, \eta^2_p = .14$, Strength $F(1,39) = 6.81, p<.05, \eta^2_p = .15$, and FRP $F(12.01,468.43) = 5.26, p<.001, \eta^2_p = .12$.

**Experiment 2 First Recall Probability Conclusions.**

In SO conditions, primacy was seen across the various lists, with stronger effects in strong words and mixed lists. Strong differences between FA and DA were apparent in mixed weak lists and pure strong lists. However, the initial words stored in the pure weak lists did not show an advantage in the full attention condition indicating three repetitions of 1 s words in FA or DA condition did not produce a noticeable difference. A difference between attention conditions in the SO mixed strong lists did not produce a large difference in contextual storage for first words studied.

**Conditional Recall Probability.**

Conditional Recall Probability (CRP) is shown in Figures 18 and 19 for pure and mixed lists for the same order (left columns) and different order (right columns) conditions below.

**Experiment 2 Same Order CRP.** Same Order conditions showed a large tendency for forward recall in the FA weak and strong pure lists as well as the strong words in mixed lists. The negligible slopes present for weak words in mixed lists show there was little reliance on IIA in both attention conditions. Divided attention in pure
lists produced shallower slopes, indicating a reduction in use of IIAs compared to the full attention condition.

Interestingly, mixed lists in either strength showed little effect of dividing attention.

![Same Order vs Different Order Graphs](image)

**Figure 18.** Exp 2 Pure Lists Conditional Recall Probability
*Note: A lag of 1 represents recalling the word presented for study immediately after the word just recalled. Different Order graphs display the CRP for the initial order studied.*

![Same Order vs Different Order Graphs](image)

**Figure 19.** Exp 2 Mixed Lists Conditional Recall Probability
*Note: A lag of 1 represents recalling the word presented for study immediately after the word just recalled. Different Order graphs display the CRP for the initial order studied.*

The most credible model from the 2x2x2x8 (Attention x List Type x Strength x Lag) Bayesian ANOVA included Attention + Strength + Lag + Strength*Lag with a BF_M of 481.95 and BF_10 of 5.60e96 (error = 1.56 %).

The strength of evidence in the data for including certain predictors in the models had strongest effects from Lag (\(\infty\)), Strength (3.5e4), and Strength*Lag (6.05e4). Additionally, the repeated-measures ANOVA produced similar main effects of Attention \(F(1,39) = 20.41, p< .001, \eta^2 = .34\), Strength \(F(1,39) = 15.44, p< .001, \eta^2 = .28\), Lag \(F(2.14, 83.63) = 44.16, p< .001, \eta^2 = .53\), and Strength*Lag \(F(3.84,149.92) = 7.11, p< .001, \eta^2 = .15\).

**Experiment 2 Different Order CRP.** The lack of forward asymmetry in the CRP curves in both mixed and pure lists for strong words was expected as IIAs should not have strengthened in spaced study. Both attention
conditions appeared similar to each other in pure lists, with small differences in forward lag positions in mixed. A 2x2x2x8 (Attention x List Type x Strength x Lag) Bayesian ANOVA determined the most credible model included the predictors of Strength + Lag with a BF of 69.63, BF10 of 2.37e17 (error = 1.27 %), and BF inclusion of 2.07e4 for Strength and 1.09e12 for Lag. The repeated-measures ANOVA differed by including Attention $F(1,39) = 10.29, p<.01, \eta^2_p = .21$ in the main effects as well as Strength $F(1,39) = 21.99, p<.001, \eta^2_p = .36$, Lag $F(5.05, 196.87) = 8.53, p<.001, \eta^2_p = .18$, and Attention*List Type $F(1,39) = 10.29, p<.01, \eta^2_p = .21$.

Conditional Recall Probability: Discussion.

As expected, DO conditions showed little if any reliance on IIA shown by the shallow slopes in forward or reverse lag directions. SO pure list words CRP graphs show use of interitem associations in the FA but use of this information was reduced in the DA conditions, with similar differences between FA and DA in pure weak and pure strong SO CRPs. The DA reduction in IIA storage indicates a disruption occurred during study preventing the buffer from sufficiently binding the information. The mixed list SO graphs show an interesting distinction between reliance on IIA for strong and weak words. Weak items in the mixed list did not show use of IIA, indicating that although words were studied three times in the same order, IIA may not have strengthened. However, this was not the case for mixed strong words, as the asymmetrical shape of the CRP curve shows that recall was typical for words lag +1 position. Although mixed weak items were recalled at better probabilities that pure weak items, the CRP curves show that IIA was not contributing to this effect.

Experiment 2 Conclusions

The null LSE that appeared from correct recall in the SO FA condition likely indicates that there was little difference in context information between strong and weak traces. This effect was unlikely to have been driven from IIA, due to lack of indication of a change in DO FA correct recall. If context accumulation occurs over separated presentations, it is possible that weak words were able to accumulate information over multiple presentations leading to a full shot of context in the strengthened trace. In contrast, abatement of accumulating contextual strength might also occur for items with multiple opportunities to store a full shot of context in each presentation. Within relatively brief spans of study in lists, context is unlikely to change drastically leading to a
temporary ceiling of information that could be accurately stored in each trace. If multiple presentations accumulate context information, weak words might have accumulated sufficient accurate information.

Traces formed when studying a word for 2 s or more have enough time for an attempt to store a full shot of context, while multiple attempts of distributed study increase context information within the trace. Evidence of primacy emphasizes this effect since the buffer is tasked to bind information to only the first word. Strong words (3 s) in Experiment 2 showed a large primacy effect in both pure and mixed strong words which was likely driven from accumulation across multiple study attempts. The primacy seen in DO pure strong words was similar to the SO pure strong, while DO mixed strong words showed a drastic reduction in primacy, indicating effects from repeating order of study may have contributed to the primacy effect in mixed lists.

Dividing attention in Experiment 2 did not produce overt changes in correct recall other than lowering overall probability. Oddities present in the Experiment 2 DA conditions are especially distinct in weak lists graphs and may have stemmed from the difficulty and the speed of numbers in the divided attention task. The DA task that was used required students to listen numbers occurring every two seconds and were tasked to listen for three odd numbers in a row and sufficiently induced disturbance during the encoding process in Sahakyan & Malmberg (2018). In the current study, the rate of presentation of numbers may have been problematic due to the short duration of weak words (1 s) potentially allowing subjects to ‘study’ weak words relatively uninterrupted. However, the DA task used in Experiment 2 still had an effect on weak words (evident by the DA reduction in Figures 12B, 13B, 15, 17, 18), which may have disrupted binding but may not have been overt enough for the subject to not update the trace during repeated study. Thus, the DA conditions were still disrupting later recall with possible differential effects in strong than weak words. In addition, this mild disruption may affect the binding process in the buffer but not be too strenuous that updating traces does not occur. If so, this should produce differences in contextual storage for strong and weak words, which could account for this small but observable +LSE in the DA conditions. As hypothesized in Malmberg & Shiffrin (2005), if strengthening IIA can contribute somewhat to the +LSE, then the disappearance of the small effect seen in SO in the DO condition would be expected.

The manipulation of study time for words repeated three times did not produce a noticeable difference in recall even when partial stores of context likely occurred. When items were studied once in Malmberg and Shiffrin (2005) for 1 or 3 s, a small LSE emerged where strong mixed traces showed an advantage of recall over pure mixed, and pure weak were better recalled than mixed weak. Additionally, when study was increased to 2 and 6 s, the
+LSE disappeared indicating there was lack of sampling advantage for strong traces rather than weak. Multiple repetitions in Experiment 2 appeared to be beneficial in strengthening the trace since accumulation appeared to reduce the effect of storing partial context. Thus, Experiment 2 appeared to show that study time, even when brief, is less detrimental in later retrieval if weak words are distributed and repeated an equivalent number of times as strong words. Experiment 3 expands on this rationale by investigating the effects of dividing attention on words when they are similar in presentation time but strengthened by number of repetitions. Malmberg and Shiffrin (2005) produced a +LSE when words were strengthened by increases in repetition (one or three repetitions) but equated in study time, and Sahakyan and Malmberg (2019) manipulated strength by massing or spacing study of words studied twice for 6 s and produced a null LSE when attention was divided. Therefore, would testing a brief study time but strengthening by multiple repetitions (one rep vs three rep) produce a similar null LSE when dividing attention during study?
Chapter Five:

Experiment 3

Experiment 3 tested the effects of attention when encoding words strengthened by number of repetitions. Experiment 2 kept repetitions constant and strengthened words by study time resulting in accumulation of context in all traces, Experiment 3 manipulated words (studied for 2 s per presentation) by the directly affecting the ability to accumulate context within each trace. Experiment 3 resembled part of Malmberg and Shiffrin (2005) where a strong +LSE was produced when items studied for 2 s were either seen once or three times in a spaced fashion. Additionally, a less robust +LSE was also produced when study order was varied. All items in the current experiment were studied for 2 s per presentation, with strong words presented three times and weak words presented once. The attention manipulation will test whether dividing attention abates this +LSE by producing many weak traces representing the repeated study of strong words. Strengthening traces where a full shot of context is possible in conditions without an additional task, distributed study should aid in forming and accumulating strong accurate contextual information in the trace leading to a +LSE in recall. However, when dividing attention, increased cognitive load should lead to a disruption of trace strengthening resulting in a set of many weak traces, therefore eliminating interference from strong traces. If order of study is not repeated, a lack of strengthened interitem associations should reduce this effect in both attention conditions.

Experiment 3 Methods

Participants

Seventy USF psychology undergraduates were recruited through Sona and received course credit for their participation.

Design

This experimental design was a 2x2x2x2 within-subjects design. The conditions were Order (same vs. different order) x Strength (strong vs. weak) x Attention (full vs. divided) x List Type (pure vs. mixed). Words
presented in the SO condition were repeated in the same order, i.e. 1-10, 1-10, 1-10, while words presented in the
different order (DO) condition were presented in the following order: 1-10; 3, 8, 2, 5, 1, 7, 10, 6, 9, 4; and 3, 1, 10,
2, 9, 5, 8, 6, 4, 7. There were eight list types within the SO condition and 8 list types within the DO condition. The
Order condition was blocked and randomized so that participants would begin the experiment with all eight SO lists
or all eight DO lists. All words were shown in white text on a black screen for a duration of 2 s with a 100 ms
interval between each presentation. Thus, total study time for words was either 2 s or 6 s. There were four list types
that were encoded under full attention and divided attention: pure weak (PW), pure strong (PS), mixed31 (ML31),
mixed13 (ML13). A PW list consisted of words presented one time each, while a PS list consisted of words
presented three times each. Mixed Lists contained 10 weak (one presentation) and 10 strong (three presentations)
words with the presentation of word strength was blocked. A mixed31 list presented the 10 strong words before the
10 weak words, while a mixed13 list presented the 10 weak words before the 10 strong words. Table 9 below shows
the experimental design.

**Table 9. Exp 3 Design**

<table>
<thead>
<tr>
<th>Design</th>
<th>List Type</th>
<th># Presentations x Study Duration</th>
<th># Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>Pure Weak</td>
<td>1 x 2 s</td>
<td>20</td>
</tr>
<tr>
<td>Different</td>
<td>Pure Strong</td>
<td>3 x 2 s</td>
<td>20</td>
</tr>
<tr>
<td>FA DA</td>
<td>PW</td>
<td>1 x 2 s</td>
<td>20</td>
</tr>
<tr>
<td>PW PS</td>
<td>Mixed</td>
<td>weak 1 x 2 s</td>
<td>10 = 20</td>
</tr>
<tr>
<td>ML13 ML31</td>
<td>ML13 ML13</td>
<td>strong 3 x 2 s</td>
<td>10</td>
</tr>
<tr>
<td>ML31</td>
<td>PW</td>
<td>1 x 2 s</td>
<td>20</td>
</tr>
<tr>
<td>ML31</td>
<td>Mixed</td>
<td>weak 1 x 2 s</td>
<td>10</td>
</tr>
<tr>
<td>ML31</td>
<td>ML31</td>
<td>strong 3 x 2 s</td>
<td>10</td>
</tr>
</tbody>
</table>

**Materials**

The experiment was written and administered using MATLAB and the Psychophysics Toolbox extension
(Brainard, 1997) software. There were 16 list variations in total for each participant. Each 20-item list was created
by randomly sampling words without replacement from a list of 1154 high frequency English words (> 19
occurrences per million; Kucera & Francis, 1967). Strong words were spaced and had a lag of 10 words for every
presentation (e.g., 1-10, 1-10, 1-10). The Order condition (Same vs. Different) was blocked so that all eight SO lists
(or eight DO lists) were encoded together. Presentation order of the list variations were randomized for each
subject. Participants were provided with standard over the ear headphones but were allowed to use their own if
preferred.
**Procedure**

All participants were tested in individual rooms on desktop computers. After obtaining consent, participants were guided through a brief practice trial by the experimenter to orient them to the main experimental procedures.

**Practice Trial.** Practice trial instructions included a description of the listening task, instruction to memorize the presented words, and instruction to attend to both the visual (words) and auditory stimuli. After an abbreviated word list, participants were told to complete simple arithmetic presented on the screen. Once 15 s elapsed (participants were not informed of time restrictions, just instructed to solve as many problems as they were able), a new screen appeared asking them to remember as many words from the recently studied list as they could. After any clarification questions had been answered, the researcher exited the room, and the participant began the experiment.

**Experiment.** Upon the beginning of each list, participants were shown the same instructions from the practice trial which included instruction to memorize the following words and instructions for the listening task (when applicable). Immediately upon conclusion of the word list (and listening task when relevant), participants completed a simple addition/subtraction distractor task for 30 seconds. Once this time elapsed, participants were given the opportunity to recall as many words as they remembered from the word list for 90 seconds (they were not informed of time restraints). A black screen with prompts stating to continue when ready appeared after the 90 s elapsed. This process was repeated until all eight list variations were completed for the particular order condition was completed. A blue screen then appeared with prompts that the participant was midway through the experiment and to continue when ready. The second Order condition was then completed in the same manner as described above.

**Divided Attention Task.** In the eight Divided Attention (DA) variations, participants wearing headphones were tasked to simultaneously monitor the sequence of digits while studying the word list. A random sequence of single digits was spoken with a female voice at a rate of 2 seconds per digit (this was the frequency used in Sahakyan & Malmberg (2018)). The task was to press a key when a pattern of three odd digits was heard. All subject’s performance on the divided attention was checked before including data in analysis to ensure attention was applied to the extra task.
Experiment 3 Results & Discussion

Correct Recall

In both the same order (SO) and different order (DO) conditions, each study attempt for a word lasted 2 s. Strength was manipulated by the number of study attempts, with strong words studied three times and weak words studied once. Pure weak (PW) lists (all words were studied once) had the same setup for both the DO and SO conditions (Bayesian ANOVAs compared for each analysis confirmed there was no credible difference). The remaining list types (pure strong (PS) and mixed (ML)) varied depending on the following conditions. Strong items (in both PS and ML) studied in the SO condition were repeated in the same order and order of study differed in the DO condition.

Experiment 3 Same Order. In the same order (SO) condition (Table 10 and Figure 20), there were a number of main effects that emerged from the 2x2x2 Attention x List Type x Strength repeated-measures ANOVA. There was a main effect of Attention $F(1,34) = 105.52, p < .01, \eta^2_p = .76$ with full attention (FA) conditions producing greater rates of correct recall. In addition, there were main effects of List Type $F(1,34) = 6.00, p < .05, \eta^2_p = .15$, Strength $F(1,34) = 180.20, p < .01, \eta^2_p = .84$, and an interaction of List Type*Strength $F(1,34) = 10.50, p < .01, \eta^2_p = .24$. Further support was shown from a Bayesian repeated-measures ANOVA revealing the most credible model to be Attention + List Type + Strength + List Type*Strength with a $BF_{M}$ of 15.64 and a $BF_{10}$ of $1.7e^{39}$ (error = 3.53 %) giving strong evidence for the model against the null. The analysis of effects showed very strong Bayesian inclusion factors coming from Attention ($BF_{inclusion} = \infty$), List Type ($BF_{inclusion} = 21.50$), Strength($BF_{inclusion} = \infty$), and List Type*Strength ($BF_{inclusion} = 39.35$) which shows the likelihood of producing the observed data in models with that particular predictor a model than models without.

As shown in Figure 20, a List-Strength Effect (LSE) emerged in both FA and DA conditions, with an unexpected and more distinct LSE in the DA condition. For both FA and DA, weak items were better recalled when in pure lists and strong items were recalled best in mixed lists. When study occurred without any distractors in FA, strong items appear to interfere with the retrieval of weak items in mixed lists, which is an expected effect in free recall. Thus, strong items should have roughly three study attempts to add new/update information context and item information in that particular trace. In free recall, retrieval for strong items have a greater likelihood of being sampled in comparison to weaker traces (Shiffrin & Steyvers, 1997). Retrieval from LTM to STM during encoding...
requires cognitive effort and the addition of extra tasks leads to a division of available cognitive resources (Craik & Byrd, 1982). Thus, when attention is divided during encoding, Sahakyan and Malmberg (2018) predicted that increased cognitive load burdens the process of retrieving and updating a previously stored trace (i.e., a word that was studied already) and instead a new trace is created. These many weak traces produced a null LSE in Sahakyan and Malmberg (2018), however this was not the case in the current experiment. This +LSE that emerged in the DA condition was unexpected.

**Table 10.** Exp 3 Same Order Correct Recall

<table>
<thead>
<tr>
<th>List</th>
<th>Strength</th>
<th>Attention</th>
<th>Full Mean</th>
<th>Full SEM</th>
<th>Divided Mean</th>
<th>Divided SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure</td>
<td>Weak</td>
<td></td>
<td>0.28</td>
<td>0.02</td>
<td>0.17</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td></td>
<td>0.51</td>
<td>0.02</td>
<td>0.31</td>
<td>0.03</td>
</tr>
<tr>
<td>Mixed</td>
<td>Weak</td>
<td></td>
<td>0.25</td>
<td>0.03</td>
<td>0.10</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td></td>
<td>0.57</td>
<td>0.02</td>
<td>0.39</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Note: Proportion of words correctly recalled from each list type with SEM.

**Figure 20.** Exp 3 Same Order Correct Recall

*Note: A) SO Full Attention B) SO Divided Attention*

**Experiment 3 Different Order.** Table 11 and Figure 21 show the free recall results in the different order condition. A 2x2x2 Attention x List Type x Strength repeated-measures ANOVA was also conducted for the Different Order (DO) conditions and revealed main effects of Attention $F(1,34) = 80.46$, $p < .01$, $\eta_p^2 = .70$, List Type $F(1,34) = 5.40$, $p < .05$, $\eta_p^2 = .14$, Strength $F(1,34) = 124.90$, $p < .01$, $\eta_p^2 = .77$, and a List Type * Strength $F(1,34) = 11.14$, $p < .01$, $\eta_p^2 = .25$ interaction. Further supporting these results were the results from the Bayesian repeated-measures ANOVA. The most credible model produced included all the previously listed effects: Attention + List Type + Strength + List Type*Strength, showing strong evidence for this model with a BF$_M$ of 12.79 and a BF$_{10}$ of $2.08e^{34}$ (error = 3.12%). The analysis of effects included very strong Bayesian inclusion factors coming from
Attention (BF inclusion: 2.64e13), List Type (BF inclusion: 27.31), Strength (BF inclusion: 5.96e13), and List Type*Strength (BF inclusion: 70.54).

A small LSE can be seen in the FA condition in Figure 21, where the effect is most prominent in strong words (recall is better for strong words from mixed lists than pure lists). The DA condition (Figure 21B) revealed a more prominent + LSE than in the FA counterpart, possibly indicating that when attention was divided, there was a greater difference between strong and weak words that created greater interference from stronger words in mixed lists. Since a different order was studied for each attempt, this +LSE in the DA condition indicate that IIAs were likely not contributing to the observed LSE.

Table 11. Exp 3 Different Order Correct Recall

<table>
<thead>
<tr>
<th>List Type</th>
<th>Strength</th>
<th>Attention</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Full Mean</td>
</tr>
<tr>
<td>Pure</td>
<td>Weak</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td>0.44</td>
</tr>
<tr>
<td>Mixed</td>
<td>Weak</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Note: Proportion of words correctly recalled from each list type with SEM.

Figure 21. Exp 3 Different Order Correct Recall
Note: A) DO Full Attention. B) DO Divided Attention.

Serial Position

Serial position curves are plotted in Figures 22 and 23. Pure lists are shown in Figure 22 while mixed lists are shown in Figure 23. The data were compiled into 10 bins representing two list positions each for ease of viewing.

Experiment 3 Same Order. Serial position curve data was tested in a 2x2x2x20 Attention x List Type x Strength x Position repeated-measures ANOVA as well as a repeated-measures Bayesian ANOVA for both the SO and DO conditions. Several effects emerged in the SO condition including Strength \( F(1,34) = 264.68, p< .01, \eta^2_p = \)
.89, Attention $F(1,34) = 103.79$, $p < .01$, $\eta^2_p = .75$, List Type $F(1,34) = 6.60$, $p < .05$, $\eta^2_p = .16$, Position $F(19,646) = 3.09$, $p < .01$, $\eta^2_p = .08$, and two interactions of Attention*List Type = $F(1,34) = 15.94$, $p < .01$, $\eta^2_p = .32$ and

Attention*List Type*Strength = $F(1,34) = 8.94$, $p < .01$, $\eta^2_p = .21$. Additionally, the most credible model produced from the Bayesian ANOVA included Attention + List Type + Strength + Position + Attention*List Type (BF$_M$ of 504.43 and BF$_{10}$ of $2.49 \times 10^{148}$, error = 3.48%). Analysis of effects from the models revealed BF$_{inclusion}$ factors of Attention (BF$_{inclusion}$: $5.26 \times 10^2$), Strength (BF$_{inclusion}$: $5.26 \times 10^2$), Position (BF$_{inclusion}$: 1828.17), List Type (BF$_{inclusion}$: 1143.04), and Attention*List Type (BF$_{inclusion}$: 1056.66).

Strength and Attention had the strongest effects for differences between conditions. Pure weak words were consistently recalled at lower rates than strong words and FA conditions consistently showed better rates of recall across conditions (evidence from the Bayesian ANOVA posteriors determined 95% credible intervals did not overlap). Additionally, SO PW FA and DA showed a small trend to recall words earlier on the list (Bayesian paired-samples t-tests showed anecdotal evidence with BF$_{10}$ ranging from 2-3). Recall in the FA condition in PS lists showed a possible recency effect while the DA condition had overall reduced recall but was fairly stable across positions.

Trends for recall in the mixed lists (Figure 23) were different from the pure lists. When in a mixed list, recall of weak words was reduced and did not show a primacy trend but appeared to be fairly stable across positions. Strong items in mixed lists tended to be recalled better at earlier positions, whereas the opposite was observed when in pure lists.

**Experiment 3 Different Order.** Due to both the SO PW and DO PW conditions being identical in list construction (i.e., 20 randomized words studied once for 2 s per word), these lists were compared to ensure that there were no differences. A 2x2x2 Order x Attention x Position repeated-measures ANOVA with Order as the between-subjects variable confirmed that there were no significant differences between SO PW and DO PW lists.

Serial position data for the DO condition was also tested by a 2x2x2x20 Attention x List Type x Strength x Position repeated-measures ANOVA as well as a repeated-measures Bayesian ANOVA. Main effects of Attention $F(1,34) = 47.40$, $p < .01$, $\eta^2 = .58$, Strength $F(1,34) = 165.54$, $p < .01$, $\eta^2 = .83$, Position $F(19,646) = 20.24$, $p < .01$, $\eta^2 = .15$, Attention*List Type $F(1,34) = 20.242$, $p < .01$, $\eta^2 = .37$, and Strength*Position $F(19,646) = 1.75$, $p < .05$, $\eta^2 = .05$. The most credible model produced included Attention + List Type + Strength + Position + Attention*List Type (BF$_M$ = 610.36 and BF$_{10}$ of $7.39 \times 10^{8}$, error = 3.24%). Analysis of effects revealed evidence for including these
predictors in the data to be Strength (BF\text{inclusion} = \infty), Position (BF\text{inclusion} = \infty), Attention (BF\text{inclusion} = 1.85e^{12}), Attention*List Type (BF\text{inclusion} = 37.24), and List Type (BF\text{inclusion} = 5.04).

As shown in the right column of Figure 22, the probability of recall across positions was greater in DO PS lists than PW lists which was supported by post hoc analyses. There appeared to be a slightly stronger tendency to recall earlier positions on pure weak DO lists than in the pure strong FA DO lists. The right two columns in Figure 23 show the serial position curves for weak and strong words in the mixed list DO conditions. Recall appeared to still be somewhat steady across positions for the mixed list strong words in the full attention condition. DO mixed list weak words however showed a strong primacy effect for both full and divided attention conditions.

When comparing pure strong conditions across SO and DO conditions, repeating the order of study did not appear to show a drastic effect on the position that was recalled. The SO PS FA condition produced a small recency effect with an increasing trend to recall words studied in the latter four positions, while the DO PS FA condition showed a slight decline in recall in the latter positions. The DA conditions in both the same and different study order had greater probabilities of recall in earlier conditions, indicating that when study order was not maintained, the first few positions studied were recalled better. The SO strong condition showed a divergence in recall towards the last 4-6 positions with better recall in FA than DA conditions, while the DO strong FA and DA lists appeared to converge in probability of recall.

However, when lists were mixed (containing both strong and weak words), trends of recall position appeared to change more for the weak words in both full and divided attention conditions. In mixed lists, when weak words were presented first before strong (i.e., positions 1-10 in the experiment, position 1-5 in Figure 23), probability of recall for weak words was better in the DO conditions than in the SO conditions. When weak words were studied second (i.e., positions 11-20, or 6-10 in Figure 23), both SO and DO FA trends were comparable with a small primacy effect for the start of that block of words.

When study was repeated in the same order, the recall in SO DA conditions for both weak and strong words was low and appeared unaffected from their order of study, while patterns in the DO DA conditions somewhat mimicked patterns in DO FA. Although average correct recall of strong words was not drastically different in the divided attention conditions (SO: 0.31 ± 0.03, DO: 0.27 ± 0.02), recall across positions showed a steadier trend in recall across positions in the SO condition indicating that strengthening IIAs benefitted later recall.
First Recall Probability

First Recall Probability (FRP) displays the probability of first word recalled for each list and can be viewed for pure lists in Figure 24 and mixed lists in Figure 25 for both SO and DO conditions.

Experiment 3 Same Order FRP. Primacy was evident in the SO lists for both PW and PS lists (left column of Figure 24), with greater probabilities of first recall occurring in the pure weak lists. When words were studied once in the SO condition, the initial word recalled tended to be the very first word studied. While this trend was still present in the PS lists, studying words more than once produced a less robust primacy effect. The effect of first recalling the initial word was not affected by dividing attention during study in either the SO PW or PS lists. Although it is expected that there will be a primacy effect due to the buffer encoding only one word to bind new
context and information, it is possible that this effect did not differ between attention conditions due to an issue in the methods. Due to a lag in the loading of the program, occasionally the DA audio file would delay and thus the first word presented may have not been accompanied with the audio task. In the PS condition, the lessened primacy effect may have occurred due to stronger traces including more accurate context throughout the entirety of list during the retrieval process. The three presentations 2 s may be driving better context storage across positions reducing the difference between the strength of context in the first item stored compared to other items. The repeated study process should strengthen context and item information in the trace, while the PW lists lacked any repetition therefore the initial words would maintain an advantage of available cognitive processes for the one attempt to bind information.

Same order mixed lists produced different trends than those in the pure lists, with a stronger primacy effect seen in strong words. If the presence of strong words cause interference with the recall of weak words in the same list, then a larger primacy effect from the strong items is not surprising. Dividing attention during the encoding process appeared to disrupt this effect of primacy seen in the mixed lists, with a greater difference between attention in the recall of mixed strong words.

A 2x2x2x20 Attention x List Type x Strength x Position repeated-measures ANOVA and Bayesian repeated-measures ANOVA was conducted to investigate these trends. The repeated-measures ANOVA produced main effects of Strength $F(1,34) = 36.726, p<.01, \eta^2=.52$, Position $F(19,646) = 8.52, p<.01, \eta^2=.20$, and an interaction of List Type*Strength $F(1,34) = 30.42, p<.01, \eta^2=.47$. The Bayesian ANOVA produced similar findings with parameters including List Type + Strength + Position + List Type*Strength ($BF_M$ of 2394.31 and $BF_{10}$

![Figure 24. Exp 3 Pure Lists First Recall Probability](image)

*Note: Position corresponds to the respective position of a word when initially studied in each list. Each list has 20 unique words. For example, position 11-12 displays the binned FRP average for the 11th and 12th unique word.*
of $3.88e^{40}$, error = 1.93 %). The analysis of effects revealed the strongest influence from List Type ($BF_{\text{inclusion}}$: 3.85); Strength ($BF_{\text{inclusion}}$: $5.8e^5$); Position ($BF_{\text{inclusion}}$: $\infty$); and List Type * Strength ($BF_{\text{inclusion}}$: 28.78).

**Experiment 3: Different Order FRP.** When order of study was not repeated (Figure 24 and 25, right column), recall of DO pure lists produced somewhat unexpected trends. PW DO lists should have shown a roughly similar pattern to that seen in the SO PW lists, however there was a much stronger primacy effect in the divided attention than in the full attention condition. Items that were studied three times in a varying order (Figure 24, bottom right) appeared to show a roughly similar primacy effect to DO PW in the full attention condition, while the divided attention condition showed a bit more variability across positions. DO mixed lists (Figure 25, right column) produced a stronger primacy effect for weak words than seen in the SO condition. Although recall was slightly greater in FA, both attention conditions showed a strong tendency to recall the first item studied on the mixed list for both strong and weak words. Strong words from DO mixed lists also produced a primacy effect, with FA showing a greater primacy effect than DA strong words.

A repeated measures ANOVA and Bayesian ANOVA was conducted to analyze the DO FRP data. There were main effects of Strength $F(1,34) = 14.75$, $p<.01$, $\eta^2 = .30$, Position $F(19,646) = 11.25$, $p<.01$, $\eta^2 = .25$, and an interaction of List Type*Strength $F(1,34) = 9.65$, $p<.01$, $\eta^2 = .004$. The Bayesian ANOVA produced the best model including only Strength + Position ($BF_M$ of 486.11 and a $BF_{10}$ of $2.94e^{45}$, error 2.29 %). Analysis of effects revealed prominent BF model inclusions from Position ($BF_{\text{inclusion}}$ of $7.79e^{44}$) and Strength ($BF_{\text{inclusion}}$ of 4.546). The best model that included the List Type*Strength as an interaction showed a $BF_M$ of only 5.43, indicating that the change
in probability of the model from the prior to the posterior was substantially less than the best model produced (which did not include this interaction). Additionally, the model including the interaction had a BF_{01} of 23.50, indicating that it was 23.50 times less likely than the Strength + Position model. Interestingly, both SO and DO FRP data did not show to have major influence from the attention conditions indicating that primacy was not largely disrupted by dividing attention during encoding in this experiment.

**Conditional Recall Probability**

The conditional recall probability (CRP) curves were plotted to show the contiguity of the participant’s free recall processes. Steep slopes in the forward direction (i.e., lag of 1-4) indicate that associations between words studied were likely encoded and subsequently utilized during retrieval. The SO FA condition should show a strong tendency to recall words that were close in position during study as the order of study was maintained. This would be indicated by a strong asymmetrical slope, with a shallow slope in the negative lag positions and a stronger positive slope in the positive lag positions. If dividing attention during study disrupted trace accumulation, then a reduction of the slope in the positive lag direction should be observed indicating that context and IIAs in the original traces were not adequately strengthened during study disrupting the likelihood of later sampling during free recall. The DO condition did not allow for the strengthening of IIAs for strong words as the order of study was not repeated. Therefore, without adequate strengthening of trace information, the DO FA and DA conditions as well as the SO DA condition should produce a reduce positive lag slope. The CRP data for pure lists were plotted in Figure 26 while the data from mixed lists were plotted in Figure 27.

**Experiment 3 Same Order CRP.** A strong asymmetrical pattern emerged in both the SO FA PW and SO FA PS lists (Figure 26, left column). Free recall from the SO FA PW condition showed a strong tendency to retrieve words studied in close temporal proximity as well as in the forward direction. However, this forward asymmetry was drastically reduced when attention was divided for pure weak lists, which was supported by a Bayesian paired samples t-test indicating evidence for a difference between recall of SO PW lag -1 and +1 was 5.23 times less likely than no difference (BF_{01}: 5.23, error = 1.02e+6%). This shows evidence that context and interitem information in the trace was likely disrupted during encoding. SO PS CRP curves showed forward asymmetry for both the FA and DA conditions indicating that dividing attention during study did not drastically disrupt later recall in this condition. In SO mixed lists (Figure 27, left column), forward recall was reduced for weak items in comparison with pure weak
lists, which may be a resultant of interference from stronger items in the mixed list. Strong items from SO mixed lists showed a strong distinction in pattern between FA and DA conditions. As expected, strong words studied when fully attentive maintained a strong asymmetric and forward trend in recall indicating accurate context and interitem associations were formed during encoding. However, dividing attention drastically reduced the curve so that recall was symmetrical in both lag positive and negative directions. A Bayesian paired samples t-test supported evidence of this symmetry with a BF$_{01}$ of 7.33 (error = 3.31e$^{-5}$ %).

The same order condition CRP data was also analyzed using a repeated measures ANOVA and a repeated measures Bayesian ANOVA. Numerous main effects and interactions were observed from the ANOVA including: Attention $F(1,34) = 37.88$, $p$.01, $\eta^2 = .53$, List Type $F(1,34) = 6.05$, $p$.05, $\eta^2 = .15$, Strength $F(1,34) = 73.38$, $p$.01, $\eta^2 = .68$, Lag $F(7,238) = 33.16$, $p$.01, $\eta^2 = .49$, Attention*List Type $F(1,34) = 4.20$, $p$.05, $\eta^2 = .11$, List Type*Strength $F(1,34) = 10.02$, $p$.01, $\eta^2 = .23$, Attention*Lag $F(7,238) = 6.10$, $p$.01, $\eta^2 = .15$, and Strength*Lag $F(7,238) = 4.73$, $p$.01, $\eta^2 = .12$. The Bayesian model produced included fewer predictors than shown above: Attention + Strength + Lag + Attention*Lag + Strength*Lag and showed strongest evidence for the data fitting the model (BF$_{M}$ of 103.19) as well as probability against the null (BF$_{10}$ of 9.84e$^{-79}$ error = 17.37 %). Analysis of effects showed strong contributions from the following predictors: Attention (BF$_{inclusion}$: 9.31e$^{6}$), Strength (BF$_{inclusion}$: 1.91e$^{10}$), Lag (BF$_{inclusion}$: $\infty$), Attention* Lag (BF$_{inclusion}$: 1.50e$^{4}$), and Strength*Lag (BF$_{inclusion}$: 74.41).

![Figure 26. Exp 3 Pure Lists Conditional Recall Probability](image)

*Note: A lag of 1 represents recalling the word presented for study immediately after the word just recalled. Different Order graphs display the CRP for the initial order studied.*

**Experiment 3 Different Order.** The CRP curves from the DO condition for pure lists are plotted in the right column of Figure 26. Although the same in composition as the pure weak list in the SO PW condition, pure weak words in the DO condition did not produce a prominent forward asymmetry in the full attention condition,
while the DA condition showed weak forward asymmetry. However, in contrast with the SO PS condition, recall in DO PS lists revealed a reduction in probability to recall words in the positive lag direction for both FA and DA conditions. Although these words were studied three times, the order of study was never repeated, so the less asymmetrical curves describe a decreased tendency to recall words studied in close proximity as each word would have multiple “neighbors” during study. The strong and weak words in the DO mixed lists in the right column of Figure 27 right show similar trends with a weak forward lag asymmetry. Although there appears to be a small tendency to recall DO FA mixed words in the positive lag direction, this effect is largely reduced from that seen in the SO condition, indicating that IIA information was not as heavily used during the free recall process. DO DA mixed strong words show little indication of a biased direction of temporal recall (Lag +1 ≠ -1 was 7.35 times less probable than the null, BF_{01} of 7.35, error 3.32e^{-5} %), likely indicating that trace accumulation was disrupted during the encoding process. The similarity between curves of the SO DA conditions and the DO FA and DO DA conditions strengthens the idea that dividing attention does impact and reduce storage of interitem associations.

The repeated measures ANOVA for the DO condition produced three main effects which included Attention $F(1,34) = 24.03, p < .01, \eta^2 = .41$, Strength $F(1,34) = 15.99, p < .01, \eta^2 = .32$, and Lag $F(19,238) = 19.03, p < .01, \eta^2 = .36$. Additionally, the repeated measures Bayesian ANOVA produced a similar model of Attention + Strength + Lag (BF_{M} of 898.32 and a BF_{10} of 9.61e^{29} (error 3.96 %) with analysis of effects showing predictor influences from Attention (BF_{inclusion} = 6.17), Strength (BF_{inclusion} = 34.64), and Lag (BF_{inclusion} = \infty). The

![Figure 27. Exp 3 Mixed List Conditional Recall Probability](image)

*Note: A lag of 1 represents recalling the word presented for study immediately after the word just recalled. Different Order graphs display the CRP for the initial order studied.*
structure/composition of the list (either pure or mixed) did not seem to largely influence the participant’s trend of recall.

**Experiment 3 Conclusions**

Experiment 3 used a mixed-pure paradigm to investigate effects of divided attention during encoding on the strength of traces and the strength/quality of interitem associations. Disrupting the ability to strengthen interitem associations (IIAs) or context-item information in the different order condition appeared successful in the experiment. Positive LSEs were present in both same and different order conditions as well as in both attention conditions. Additionally, participants’ probabilities of correct recall between same and different order conditions were not drastically different indicating that IIAs may not be a leading contributor to the positive LSE typically observed from free recall tasks. Rationale for the current study was built off of Sahakyan & Malmberg (2018) which found that dividing attention during study disrupted trace accumulation evident from a null LSE in recall and +LSE in recognition. However, results from this experiment show large +LSE in both same and different order divided attention conditions. The discrepancy between results may have occurred due to the amount of time spent studying each word; participants from Sahakyan & Malmberg (2018) studied words 6 s at a time twice (total study time of 12 s), whereas participants in the current experiment studied words for 2 s, either once or three times (total study time of 2 or 6 s).

Since it is likely that dividing attention creates additional strain by increasing cognitive load, the participant’s ability to update an existing trace during study is reduced. Thus, a situation is created where the easier option is to create a new trace rather than retrieving and updating the existing trace. This disrupted process leads to multiple weak traces representing an item studied across multiple attempts, which would lead to a null or slightly negative LSE (Sahakyan & Malmberg 2018). Since this was not the case in Experiment 3, it is possible that the difficulty of the divided attention task did not induce enough cognitive load that would sufficiently disrupt the binding processes in the buffer. However, all participants’ performance on the DA task was checked for accuracy before being included in the analysis. Alternatively, it is also plausible that increases in study time per attempt increase the chances of binding unwanted/other information to the trace (i.e., features from the simultaneous audio task). This extra information would be noise, making the trace more difficult to match a contextual cue with the contents of the stored trace. If this scenario were the case, an increase in study time while attention is divided for
each attempt may increase this risk of the addition of unwanted information (noise) to the trace, while shorter durations of each study attempt would reduce this probability, leading to a less noisy trace to available during sampling in the free recall process.

Primacy effects give indication that initial context was stored correctly and more accurately in the first few items during study than the later items. Pure strong lists for both SO and DO conditions did not show a strong tendency for first recall of early items on the list in either FA or DA conditions indicating that repeating the order of study or addition of an extra task did not affect the participant’s tendency to later recall the earlier words for pure lists. However, a different trend was present for strong items in mixed lists. Interference from strong traces in the mixed lists appeared to produce a strong primacy effect for recall of strong words under the SO FA condition. When the order of study was not maintained for DO strong words, the difference between FRPs in strong and weak words was less evident.

Lastly, disrupting the original order of study successfully reduced the asymmetry of a typical CRP curve in pure and mixed lists. DO pure strong lists showed little difference between attention types, indicating the addition of an extra task during study did not further disrupt the binding of IIA s or context. Mixed list CRPs showed that the strengthening of only some words altered the trends observed in pure lists. CRP for SO weak words in both attention conditions was reduced, while the strong words showed a large tendency to recall from the +1 lag. Alternatively, this asymmetry disappeared in the DO condition, thus showing that the tendency to recall words from the initial order of study was reduced.
Chapter Six:
Replication of Sahakyan and Malmberg (2018)

Replication Method

Due to unexpected results from Experiments 2 and 3, a replication of Sahakyan & Malmberg (2018) was suggested prior to conducting Experiments 4, 5, and 6. The current replication held to the previous findings and are reported below.

Participants

**Free Recall.** Sixty-four undergraduates were recruited through the Sona research pool at the University of South Florida. They were compensated with course credit for their participation. All participants were randomly assigned to full or divided attention conditions.

**Recognition.** Sixty-one undergraduates were recruited through the Sona research pool at the University of South Florida and were compensated with course credit for participation. All participants were randomly assigned to full or divided attention conditions.

Design

The setup for the experiments was intended to replicate Sahakyan & Malmberg (2018) as closely as possible.

**Free Recall.** The experimental design included List (pure vs mixed) x Strength (strong vs weak) x Attention (FA vs DA) mixed-pure design, with Attention as the only between-subjects factor. The word bank comprised of 72 words ranging between four and seven letters in length and word frequency had a median of 29 and an interquartile range of 56.26. Three lists were randomly constructed of 24 words for each participant. Weak words were massed, and a pure weak list contained 24 words presented back-to-back. Strong words were spaced, and a pure strong list comprised of 24 items that were repeated twice with a lag of seven words. A mixed list was
constructed of 12 strong and 12 weak, all presented twice either as spaced (strong) or massed (weak). Each tercile of the mixed lists consisted of an equal number of strong and weak words. Mixed lists began with strong or weak words equally often. All three list presentations were counterbalanced.

**Recognition.** The design of the recognition experiment included Attention (FA vs DA) x List (pure vs weak) x Strength (weak vs strong) mixed-pure design. The presentation order and construction of mixed lists was the same as in the free recall experiment but without the rating task during study. The word bank included 144 words from that matched the same requirements for length (between four and seven letters) and frequency (median = 29 and interquartile range = 56.25) as in the free recall experiment and were used interchangeably as target or distractor items. Words were presented for 2 s on a black screen.

**Procedure**

The procedures matched the Sahakyan and Malmberg (2018) experiment.

**Replication Results**

**Replication: Free Recall**

Sahakyan and Malmberg (2018) produced a significant positive list-strength effect (LSE) in the full attention (FA) condition and a non-significant null to slightly negative LSE in the divided attention (DA) condition. Results from the current free recall replication can be seen in Figure 28 and Table 12. There was a main effect of Attention $F(1,62) = 11.65, p < 0.001, \eta^2 = 0.08$ where recall was lower in DA condition. Additionally, there were two interactions Strength*Attention $F(1,62) = 4.02, p = 0.05, \eta^2 = 0.01$ indicating a LSE and List*Strength*Attention $F(1,62) = 20.83, p < 0.001, \eta^2 = 0.03$ revealing that Attention mediated this interaction.

In the Full Attention (FA) condition, there was a main effect of Strength $F(1,31) = 7.03, p = .01, \eta^2 = .18$ and significant interaction of List*Strength $F(1,31) = 16.10, p < .001, \eta^2 = .34$. Strong items were better recalled on mixed than pure lists, $t(31) = 3.01, p < .001$, Cohen’s $d = .53$ and weak items were better recalled on pure lists, $t(31) = 2.38, p = .01$, Cohen’s $d = .42$ indicating a positive LSE was present.

The previous free recall experiment in Sahakyan & Malmberg (2018) found a significant main effect of Strength, but no List*Strength interaction in the DA condition. However, the strengthening and weakening components typically seen in +LSE were absent in the DA condition. This pattern was also present in the current
replication. Although Strength was not a main effect, $F(1,31) = .13, p = .72$, the interaction was significant, List*Strength $F(1,31) = 5.36, p = .03, \eta_p^2 = .15$. Strong items were not better recalled on mixed lists $t(31) = .97, p = .17$, Cohen’s $d = .17$, but weak items were better recalled on mixed lists $t(31) = 1.74, p = .05$, Cohen’s $d = .31$. This pattern of recall for weak and strong words in the DA condition is indicative of a small negative LSE.

**Table 12.** Replication: Free Recall Correct Recall

<table>
<thead>
<tr>
<th>List</th>
<th>Strength</th>
<th>Attention</th>
<th>Full Mean</th>
<th>SEM</th>
<th>Divided Mean</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA N</td>
<td>Pure</td>
<td>Weak</td>
<td>0.43</td>
<td>0.03</td>
<td>0.30</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td></td>
<td>0.41</td>
<td>0.03</td>
<td>0.33</td>
<td>0.03</td>
</tr>
<tr>
<td>DA N</td>
<td>Mixed</td>
<td>Weak</td>
<td>0.36</td>
<td>0.03</td>
<td>0.36</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td></td>
<td>0.52</td>
<td>0.04</td>
<td>0.30</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Note: Proportion of words correctly recalled reported with standard error of the mean.

**Figure 28.** Replication: Free Recall Correct Recall

The lack of strengthener in the DA condition was a new outcome that was not present in the original experiment. A lack of strengthener would indicate that there was no effect to spacing when attention was divided during study, supporting the hypothesis that spaced traces were not being strengthened. As reported below, there was however an effect of spacing (the strengthener) during the recognition condition. There was a drastic difference between understanding of the tasks to be perform in the free recall and recognition experiments. Participants in the recognition experiment were much quicker to understand the directions, whereas this was not the case for the participants who went through free recall. Although the practice trial was set up to teach them what was expected of them, there were often occurrences of needing to go through the directions again or participants were obviously stressed while learning what they were to do. Only the students who were able to understand and perform the various tasks were included in the data, but this may indicate that the added rating task during study (which was not a part of the recognition replication) did not ultimately function as a deep processing task and instead aided in
increasing cognitive strain. This extra increase in cognitive strain would have made it even more difficult for students to encode each item well, especially in the spaced condition.

**Replication: Recognition**

Sahakyan and Malmberg (2018) hypothesized that if dividing attention was affecting the accumulation of information in a single trace, then differentiation between traces would decrease and a positive LSE would emerge when tested via recognition. The Sahakyan and Malmberg (2018) experiment produced a null but slightly negative LSE in the FA condition and a positive LSE in the DA condition.

The current recognition replication is shown in Figure 29 and Table 13 below. There was a main effect of Attention \(F(1,60) = 22.17, p < .001, \eta^2 = .19\) and Strength \(F(1,60) = 16.04, p < .001, \eta^2 = .02\). There were no significant interactions, however, the List*Strength*Attention interaction fell just short of significance, \(F(1,60) = 2.98, p = .09\). Participants in the divided attention (DA) had poorer recognition accuracy than the full attention (FA) condition.

**Table 13. Replication: Recognition d’Prime**

<table>
<thead>
<tr>
<th>List</th>
<th>Strength</th>
<th>Attention</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Full</td>
<td>Divided</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dPrime</td>
<td>SEM</td>
<td>dPrime</td>
</tr>
<tr>
<td>FA N</td>
<td>Weak</td>
<td>Pure</td>
<td>2.85</td>
<td>0.14</td>
</tr>
<tr>
<td>32</td>
<td></td>
<td>Mixed</td>
<td>2.96</td>
<td>0.13</td>
</tr>
<tr>
<td>DA N</td>
<td>Strong</td>
<td>Pure</td>
<td>3.26</td>
<td>0.10</td>
</tr>
<tr>
<td>29</td>
<td></td>
<td>Mixed</td>
<td>3.11</td>
<td>0.12</td>
</tr>
</tbody>
</table>

*Note:* Recognition accuracy reported with standard error of the mean.

**Figure 29. Replication: Recognition d’Prime**

Strength was the only main effect in the FA condition, \(F(1,32) = 12.83, p < .01, \eta^p^2 = .29\). Strong items were not recalled better on mixed lists \(t(32) = .74, p = .77\), however, like Sahakyan and Malmberg (2018), there was a small effect of numerical advantage for strong words on pure lists (Cohen’s \(d = .13\)). Weak words were not better
recognized on pure than mixed lists, $t(32) = .91, p = .82$ and there was a small effect for better recognition accuracy for weak words on mixed lists (Cohen’s $d = .16$).

The patterns produced from the divided attention (DA) conditions emulated the patterns produced in Sahakyan and Malmberg (2018). There was a significant main effect of Strength in the DA condition, $F(1,28) = 4.69, p = .04, \eta_p^2 = .14$ and no significant interactions. However, weak items had greater recognition accuracy on pure than mixed lists, $t(23) = 2.31, p = .02$, Cohen’s $d = .47$. Overall, the results of the Sahakyan & Malmberg (2018) replication were successful, especially since the current free recall experiment produced stronger evidence of the effects produced in Sahakyan & Malmberg (2018).
Chapter Seven:

Experiment 4

The unexpected results in Experiment 2 could be explained by dividing attention (DA) affecting context accumulation differently between word strengths, or, by the rate of the DA task allowing for less disruption of weak traces. Since the DA listening task presented numbers every 2 s while words were presented for 1 s (weak) or 3 s (strong), many opportunities to store weak traces uninhibited are likely to occur and the small +LSE in the DA condition was due to experimental error. In contrast, it is also possible that if some context can still store even if presented below the time that a full shot of context would require, then multiple spaced presentations could lead to accurate and full ‘shot’ of context information which could explain the null LSE in the FA condition in Experiment 2. If dividing attention reduces the accuracy of these incremental additions, then weak items would likely be subjected to greater accumulation disruption than strong words. Therefore, Experiment 4 is a replication of Experiment 2 but with a more difficult (faster) DA task. Sahakyan & Malmberg (2018) also tested this more difficult DA task (1 s per number) and found that effects from the ‘harder’ task exacerbated results found from the ‘easier’ task (2 s per number). Using this faster task should reduce the issues in timing presented in Experiment 2 so that weak words presented for 1 s at a time on screen will almost always have some overlap with the spoken numbers from the listening task, rather than only intermittently. If Experiment 2’s results were effectively inducing strain for both word strengths, then these outcomes should replicate again but with exacerbated differences in the DA conditions. A significant +LSE should emerge in both the DA same order and different order conditions. There will be no expected change in the FA conditions.

If Experiment 2’s findings are replicated, this presents additional evidence that the context used during a free recall task can be sufficiently strengthened even when a single study attempt is not long enough for a full shot of context to store. This slow buildup of contextual information over multiple study attempts still implies that accumulation does lead to increases in the accuracy of context, but also that several “full shots” of context (e.g., as in the strong words) may reach a plateau of available contextual information that can be added to the trace (specifically over a short period of time of total study). For example, items studied for 1 s once or three times in
Malmberg and Shiffrin (2005) created enough contextual difference in the traces to produce a +LSE, while 1 s words studied once or massed 3 successive times in a row produced a null LSE. If study all occurs within several minutes, contextual drift may not change enough across multiple distributed study attempts. Therefore, words studied for time long enough to attempt a full contextual shot may reach this plateau of accumulation more quickly than the items that were able only to get a partial amount of context during a single attempt.

**Experiment 4 Methods**

**Participants**

Fifty-five undergraduate students from the psychology department were recruited from SONA to participate in the study. They received course credit for participating. Seventeen participants were dropped from the analysis which was either due to technical error, failure to understand the tasks, or failure to meet the minimum requirements in the DA task which was at least 75% performance.

**Design**

Experiment 4 varied the following within-subjects conditions: Study Order (same vs different) x Attention (full vs divided) x List Type (pure vs mixed) x Strength (strong, 3 s vs weak, 1 s). Study Order, List Type, and Strength conditions was the same as Experiment 2. The Divided Attention condition was updated to include a faster, more difficult listening task (described below).

**Materials**

The experiment was written using the MATLAB and with the Psychophysics Toolbox extension (Brainard, 1997) software. List composition was the same as in Experiment 2, with 20-item word lists created from a 1154 high-frequency master list. Participants were provided with standard over the ear headphones but were allowed to use their own if they preferred. The button for the DA task was on a small analog joystick device.

**Procedure**

**Practice Trial and Experiment.** The practice trial and experiment are identical to Experiment 2.
**Divided Attention Task.** The Divided Attention (DA) was administered in the same way as in Experiment 2, except the rate of numbers heard was 1 s per digit (in comparison to 2 s per digit previously). All participant’s performance was checked before including their data in the analysis to ensure attention was also applied to the extra task.

**Experiment 4 Results**

In the three experiments below, analysis variables such as Lag or Position often violated sphericity, so Greenhouse-Geisser sphericity corrections are reported for these when appropriate. Additionally, all error rates for Bayesian models were below 4%, which is sufficiently below the acceptable error rate of 20%. Direct comparisons between Experiment 2 and 4 of all graphs are available in the Appendix.

**Correct Recall**

The correct recall results are shown in Figure 30 and Table 14. The results from the full attention (FA) condition are in the left column, divided attention (DA) is in the right column, the same order (SO) condition is in the top row, and the different order (DO) condition is in the bottom row. Overall, there was a main effect of Attention $F(1, 37) = 95.48, p < .00001, \eta_p^2 = .16$ with evidence that dividing attention reduced recall in both order conditions. In addition, Strength $F(1, 37) = 256.63, p < .0001, \eta_p^2 = .87$, Order $F(1, 37) = 7.18, p = .01, \eta_p^2 = .10$, Attention*Strength $F(1, 37) = 6.79, p = .01$, and Order*Attention*Strength $F(1, 37) = 4.82, p = .03, \eta_p^2 = .12$ were also significant effects. The most credible Bayesian model included Order + Attention + Strength + Attention*Strength, $BF_{10} = 3.84e^{35}$. The analysis of effects showed supporting evidence for Attention ($BF_{inclusion} = \infty$), Strength ($BF_{inclusion} = \infty$), Order ($BF_{inclusion} = 4.43$), and Attention*Strength ($BF_{inclusion} = 4.91$).

In the same order (SO) condition (top row of Figure 30), there were main effects of Strength $F(1, 37) = 121.65, p < .0001, \eta_p^2 = .77$ and Attention $F(1, 37) = 56.80, p < .0001, \eta_p^2 = .61$. There was not a significant List*Strength interaction. In the SO DA condition, strong words were better recalled in mixed lists $t(37) = 2.56, p < .01$, Cohen’s $d = .42$, and there was slight evidence for weak words having better recall on pure lists (Cohen’s $d = .20$). The most credible Bayesian model included only Attention + Strength, $BF_{10} = 1.55e^{33}$ with the analysis of effects revealing supporting probabilities for Attention ($BF_{inclusion} = \infty$) and Strength ($BF_{inclusion} = \infty$).
In the different order (DO) condition (bottom row of Figure 30), there were main effects of Strength $F(1,37) = 182.42, p < .0001, \eta_p^2 = .83$, Attention $F(1,37) = 88.36, p < .0001, \eta_p^2 = .70$, and Attention*Strength $F(1,37) = 16.75, p < .001, \eta_p^2 = .31$. The most credible Bayesian model similarly included Attention + Strength + Attention*Strength ($BF_{10} = 1.59e^{42}$). The analysis of effects produced strong probabilities for all included variables: Attention ($BF_{\text{inclusion}} = \infty$), Strength ($BF_{\text{inclusion}} = \infty$), and Attention*Strength ($BF_{\text{inclusion}} = 159.39$).

Table 14. Exp 4 Correct Recall

<table>
<thead>
<tr>
<th>List</th>
<th>Strength</th>
<th>Attention</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full</td>
<td>Divided</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
</tr>
<tr>
<td>Same Order</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure</td>
<td>Weak</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td>0.53</td>
</tr>
<tr>
<td>Mixed</td>
<td>Weak</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td>0.53</td>
</tr>
<tr>
<td>Different Order</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure</td>
<td>Weak</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td>0.50</td>
</tr>
<tr>
<td>Mixed</td>
<td>Weak</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>Strong</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Note: Proportion of words correctly recalled reported with standard error of the mean.

Figure 30. Exp 4 Correct Recall

Note: Left column: FA. Right column: DA. Top row: SO. Bottom row: DO.

The purpose of running Experiment 4 was essentially to test the findings from Experiment 2. A more difficult listening task was used in the current experiment’s DA condition in hopes that it would exacerbate the results, however, it made little difference in results. The correct recall graphs were almost identical, with a null LSE in the FA condition and a small but not-significant LSE in the DA condition. In Experiment 2, the DO FA condition produced a null LSE, but in the current experiment, a small but not-significant LSE was produced. The
experimental FA conditions were identical between the two experiments, so these results are likely due to general variance.

Original predictions for the current experiments were derived mainly from the findings in Malmberg and Shiffrin (2005) and Sahakyan and Malmberg (2018). Given that weak words (1 s) were presented at or shorter than the estimated time to fully store a shot of context (between 1-2 s) and strong words (3 s) were presented for longer than the estimated time (Malmberg & Shiffrin, 2005), three spaced repetitions for both weak and strong words would exacerbate the difference of contextual storage between word strengths. This difference in context accumulation would drive a positive LSE in the FA condition. However, if dividing attention leads to no accumulation and a new trace formed for each iteration studied, then a null or negative LSE is predicted. Experiment 2 and 4 did not produce positive LSEs in the FA condition nor did they show a distinct null or negative LSEs in the DA condition. The DO conditions for the full and divided attention conditions were slightly different from Experiments 2 to 4, but this difference was small due to overlapping SEMs in the FA condition.

Serial Position

Analysis of recall across serial position for mixed and pure lists are displayed in Figures 31 and 32. A repeated-measures ANOVA determined there were several main effects including Strength $F(1,37) = 256.60, p < .0001, \eta_p^2 = .87$, Attention $F(1,37) = 96.33, p < .0001, \eta_p^2 = .72$, Order $F(1,37) = 7.48, p < .01, \eta_p^2 = .27$, and one three-way interaction between Order*Attention*Strength $F(1,37) = 5.65, p = .02, \eta_p^2 = .13$. Overall, dividing attention reduced recall in comparison to the full attention condition without largely disrupting the patterns across positions. Recall of middle positioned words appear to dip in several conditions with greater recall either in the first or last six positions, showing patterns indicative of primacy and recency. Direct comparisons of Experiment 2 and 4 serial position data is also available in the appendix (Figure A8 and A9). Overall trends were similar between experiments including in the divided attention conditions. Doubling the speed of the listening task did not appear to greatly affect recall across positions.
First Recall Probability

Figures for Experiment 4 First Recall Probability (FRP) are displayed below (Figure 33 and 34). There were strong tendencies to recall the first words on lists, including lists in the different order (DO) condition. In the same order (SO) condition, the greatest probability to recall the first position was in pure weak lists and strong words in mixed lists. The effects of dividing attention did not overtly reduce this recall probability across lists except in pure strong lists in the SO condition.

**Figure 31.** Exp 4 Pure Lists Serial Position

*Note: Positions correspond to the respective position of a new unique word when first encountered for each list. Each list has 20 unique words. For example, position 1-6 displays the binned average for the first 6 words studied.*

**Figure 32.** Exp 4 Mixed Lists Serial Position

*Note: Positions correspond to the respective position of a new unique word when first encountered for each list. Each list has 20 unique words. For example, position 1-6 displays the binned average for the first 6 words studied.*
An Order (2) x Attention (2) x List (2) x Strength (2) x Position (5) ANOVA revealed significant main effects of Position $F(1.21,44.63) = 26.93, p < .0001, \eta^2 = .42$, Order*List $F(1,37) = 6.00, p = .02, \eta^2 = .14$, and List*Strength*Position $F(1.56,57.65) = 4.38, p = .02, \eta^2 = .11$. The primacy effect seen across positions was expected in the full attention conditions. Dividing attention during study should inhibit the participants ability to accurately encode information, thus reducing the primacy effect. Considering all participants included correctly performed at least 75% of the listening task, it is possible that the participants who performed well had less trouble with the listening task.

**Figure 34.** Exp 4 Pure Lists First Recall Probability

*Note: Positions correspond to the respective position of a new word when first encountered for each list. Each list has 20 unique words. For example, position 11-12 displays the binned average for the 11th and 12th unique word.*

**Figure 33.** Exp 4 Mixed Lists First Recall Probability

*Note: Positions correspond to the respective position of a new word when first encountered for each list. Each list has 20 unique words. For example, position 11-12 displays the binned average for the 11th and 12th unique word.*
Conditional Recall Probability

The conditional recall probability (CRP) curves are plotted in Figures 35 and 36 to show the probability to recall adjacent words after the retrieved word (i.e., lag). When words have large amounts of accurate context and interitem associations, words are likely to be recalled in the forward direction and most likely close to other words that were studied in temporal proximity. SO CRPs are plotted in the left column of Figure 35 and 36. Since order of study was repeated in this condition, the strong positive curve is expected and expected to be diminished in the DO conditions. Additionally, if dividing attention is affecting the accumulation of accurate information in a word trace, CRP curves should also be diminished in the DA conditions. Figure 37 shows CRP for mixed lists with both word strengths to show overall CRP for these lists.

Statistical analyses were done only for lags -2 through +2 due to complexity of the data and computational power. The Order (2) x Attention (2) x List (2) x Strength (2) x Lag (4) repeated-measures ANOVA revealed multiple main effects including Order $F(1,37) = 41.27, p < .0001, \eta^2_p = .53$, Attention $F(1,37) = 41.93, p < .0001, \eta^2_p = .53$, Strength $F(1,37) = 42.76, p < .0001, \eta^2_p = .54$, and Lag $F(1.21,44.95) = 41.19, p < .0001, \eta^2_p = .53$. There were also three significant interactions including Order*Lag $F(1.41,52.26) = 23.11, p < .0001, \eta^2_p = .38$, Attention*Lag $F(1.65,61.19) = 7.46, p < .0001, \eta^2_p = .17$, and Strength*Lag $F(1.56,57.80) = 3.76, p = .04, \eta^2_p = .09$. The effects of strengthener and order of study is easily seen when comparing the CRP curves for both pure and mixed lists for the same and different conditions. There was a strong tendency for the recall of first lag position for SO words, whereas the slope of the curve was often greatly reduced in the DO conditions. Bayesian paired-samples

Figure 35. Exp 4 Pure Lists Conditional Recall Probability
Note: A lag of 1 represents recalling the word presented for study immediately after the word just recalled. DO CRP curves were calculated using the positions from the first order of study.
t-tests found credible differences between Attention conditions in the +1 lag position for SO pure strong ($BF_{10} = 5.07$), SO mixed weak ($BF_{10} = 11.15$), DO pure strong ($BF_{10} = 3.43$), and DO mixed strong ($BF_{10} = 3.44$).

![Figure 36. Exp 4 Mixed Lists Conditional Recall Probability](image)

*Note: A lag of 1 represents recalling the word presented for study immediately after the word just recalled. DO CRP curves were calculated using the positions from the first order of study.*

![Figure 37. Exp 4 Mixed Lists Combined Conditional Recall Probability](image)

Comparisons of CRP curves between Experiment 2 and 4 can be viewed in the appendix in Figures AX and AX as well. Dividing attention during study did reduce the tendency to recall the next position on the list in the SO conditions, indicating that the disruption in encoding was evident in interitem associations. Although asymmetry was still mostly present in the DA SO conditions, the tendency for probable next recall in the +1 lag position was completely disrupted in the DO condition.

**Experiment 4 Discussion**

Considering Experiment 4 was almost identical to Experiment 2 with the main difference of a faster listening task in the DA conditions, it was interesting to find such similar results. In both experiments, weak words
were presented for 1 s and strong for 3 s, which are above and at/or below the estimated time that it takes to store a full shot of context (Malmberg & Shiffrin, 2005). Importantly, all words were spaced and repeated three times. By separating out each successive repeat, the participant would need to retrieve the original trace from their long-term store into working memory to encode additional information. Additional separation between study increases the chances of changes in context (e.g., time) thus generalizing the context information stored in that trace (Raaijmakers, 2003; Lehman & Malmberg, 2011). However, if weak words traces did not have full shots of context stored, a +LSE would be expected in the FA condition similar to the result of the third experiment in Shiffrin and Malmberg (2005). When words were studied once for either 1 or 3 s, a + LSE was produced in Malmberg and Shiffrin (2005), as well as when weak words (1 s) were studied once and strong words (1 s) were spaced three times. The null LSE produced in correct recall results in Experiments 2 and 4 indicate that spaced repetition likely still adds context to the trace, even when studied as briefly as 1 s.

If dividing attention during study causes enough cognitive strain that prevents the updating of a trace, all word traces from study will be weak, therefore a preference in sampling should not occur and thus a null LSE would be predicted (Sahakyan & Malmberg, 2018). A null LSE was present in the DA DO condition, but a small positive LSE was present in the SO DA condition. The conditional recall probability (CRP) curves were also similar between Experiments 2 and 4 in the DA conditions. The CRP curves showed a tendency for forward recall to be diminished in the DA SO and DO conditions in comparison to full attention, indicating that there was enough disruption of accumulating item-item information when attention was divided. Still, increasing the speed of digits in the listening task did not induce enough difficulty for there to be a substantial difference in outcomes.

Considering the Sahakyan and Malmberg (2018) experiment replicated, it is possible that the faster listening task was still not quite difficult enough for participants. In the Sahakyan and Malmberg (2018) free recall, participants were required to rate words as they studied as well as perform the listening task. Since deep-level processing can lead to the formation of shallower and less semantically elaborate traces when attention was divided (Naveh-Benjamin, 2003), omitting this extra trace impairment may lead to the current results. The rating task seems trivial, but the requirement to switch attention to rating, continuing study, as well as monitoring the task may have added the extra cognitive strain needed to disrupt traces strengthening and produce a null or slightly negative LSE.
Chapter Eight:

Experiment 5

Experiment 5 tested the claim that strong traces are not strengthened when attention is divided during study. Results from Experiment 3 suggest that either the divided attention task was not inducing enough strain on the participant to disrupt encoding or possibly that accumulation still occurred but was not as efficient. The current experiment equated total time studied\(^5\), but manipulated the number of times an item is studied. Weak words were studied once for 6 s total while strong items will be studied 6 times for 1 s. Strong items were also spaced to allow for contextual accumulation to occur. A strong +LSE was expected in the FA condition. Whereas in the DA condition, if information binding is disrupted and updating traces does not occur, then the findings from Sahakyan and Malmberg (2018) would be replicated. The disruption of updating traces would result in six weak traces representing a single word, thus the memory set would lack interference from strong traces and produce a null LSE. Alternatively, the problem in Experiment 3 may have resulted from a large difference in possible contextual storage (one or three repetitions) such that 2 s of study time per word was too brief to undergo the same binding disruptions as words studied for 6 s, as in Sahakyan and Malmberg (2018). This will be addressed with the 1 s or 6 s of study time. Additionally, both divided attention difficulties (easy and hard) were tested to ensure that the DA tasks induced disruption.

Experiment 5 Method

Participants

Eighty undergraduate psychology students from the University of South Florida signed up to participate through the SONA system. They were compensated with course credit for their participation. Eight participants were dropped from inclusion in the analysis for failing to understand the task, technical error, or not completing the study.

\(^5\) Equated study time occurred in Sahakyan and Malmberg (2018) which items studied in a massed or spaced fashion were studied twice for 6 s per word, or 12 s total study time in strong (spaced) and weak (massed) words.
minimum performance in the divided attention task (at least 75%). The original goal of 70 was overshot by two, ending with 36 in the hard condition and 36 in the easy condition.

**Design**

Experiment 5 contained multiple manipulation including attention Difficulty: easy vs hard, Attention (full vs divided), List Type (pure vs mixed), and Strength (strong, 1 s x 6 reps vs weak, 6 s x 1 rep). Difficulty was the only between-subjects factor. The easy condition presented the listening task with a number rate of 2 s per number, while the hard task presented the task with 1 s per number. All other variables in the study were within-subject. Each subject received a mixed-pure design for both full and divided attention conditions. Table 15 below shows the experimental design for Experiment 5.

<table>
<thead>
<tr>
<th>Design</th>
<th>List Type</th>
<th># Presentations x Study Duration</th>
<th># Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy</td>
<td>Hard</td>
<td>Pure Weak</td>
<td>1 x 6 s</td>
</tr>
<tr>
<td>FA</td>
<td>DA</td>
<td>FA</td>
<td>6 x 1 s</td>
</tr>
<tr>
<td>PW</td>
<td>PW</td>
<td>PW</td>
<td>weak</td>
</tr>
<tr>
<td>PS</td>
<td>PS</td>
<td>PS</td>
<td>6 x 1 s</td>
</tr>
<tr>
<td>ML13</td>
<td>ML13</td>
<td>ML13</td>
<td>strong</td>
</tr>
<tr>
<td>ML31</td>
<td>ML31</td>
<td>ML31</td>
<td></td>
</tr>
</tbody>
</table>

**Materials**

Experiment 5 was also written in MATLAB and with the Psychophysics toolbox extension (Brainard, 1997) software. There were eight lists presented per participant and each lists contained 20 words each, randomly compiled from a list of high-frequency English words (> 19 occurrences per million; Kucera & Francis, 1967). Presentation order of list type was randomized, as well as whether they began with the full attention or divided attention condition. The button for the DA task was on a small analog joystick device.

**Procedure**

**Practice Trial.** Participants were administered the practice trial and experiment in an individual room on desktop computers. Practice trial instructions included a description of the listening task, instruction to memorize the presented words, and to attend to both the visual (words) and auditory stimuli. Participants received three small practice lists consisting of three words: one without the listening task, one with the easy listening task, and on with
the sped up ‘hard’ listening task. After each word list, participants were told to complete simple arithmetic presented on the screen. Once 15 s elapsed, the screen changed and now asked them to type out as many words from the recently studied list as they could. After any clarification questions had been answered, the researcher exited the room, and the participant began the experiment.

**Experiment.** Instructions were provided before each section began, and a prompt was provided to notify the participant whether a listening task was next. Each list was followed by an simple arithmetic distractor task for 30 s, and then a 90 s free recall page. FA and DA conditions were blocked, but list type (pure weak, pure strong, mixed 31, or mixed 13) were randomized in order. FA and DA conditions started for participants equally often. Participants were not told whether they were in the ‘fast’ or ‘slow’ listening task condition, and the directions given for the task were the same.

**Divided Attention.** During four Divided Attention (DA) lists, participants were tasked to simultaneously monitor the sequence of digits via headphones and to study the word list. A random sequence of single digits was spoken with a female voice at a rate of 2 seconds per digit in the easy condition and 1 s per digit in the hard condition. Participants were to press a button whenever three odd digits were heard. All subject’s performance on the divided attention was checked before including data in analysis to ensure attention was applied to the extra task.

**Experiment 5 Results**

Experiment 5 tested contextual accumulation in a trace by equating total study time for a word and manipulating strength by either massing study all at once (weak words, 6 s) or spacing the word six times (strong words, 1 s). There were two divided attention conditions (easy and hard) which was the only between-subjects condition. Difficulty refers to the divided attention task, either 2 s per number (easy) or 1 s per number (hard). Attention will refer to the full and divided attention conditions. Results reported in the sections below include both frequentist and Bayesian ANOVAs with the error rates for Bayesian models all below 5%. Difficulty (2) x List (2) x Strength (2) mixed ANOVAs were conducted to investigate any differences between the easy and hard DA tasks only (FA is not included in this analysis). Otherwise, Attention (FA vs DA) x List (Pure vs Mixed) x Strength (Strong vs Weak) repeated-measures ANOVAs were utilized to investigate effects within the easy or hard Difficulty conditions.
Correct Recall

The correct recall results for Experiment 5 are presented in Table 16 A and B and Figure 38 A and B. A mixed ANOVA and Bayesian ANOVA were used to investigate any differences in the probability of correctly recalling words between Difficulty conditions. The only significant main effects were Strength $F(1,70) = 39.41, p < .0001, \eta^2 = .06$ and the interaction List*Strength $F(1,70) = 7.72, p < .01, \eta^2 = .01$. Difficulty was not significant ($p = .10$), indicating there was little difference in the probability of correct recall between the easy and hard conditions. List- Strength Effects patterns emerged in both Attention conditions, however the probability of recall for weak words in the DA easy condition were equivalent while the differences between lists and word strengths were reduced in the DA hard condition.

In the easy condition (Figure 38A), there was a main effect of Attention $F(1,35) = 52.82, p < .0001, \eta_p^2 = .60$, List $F(1,35) = 4.11, p = .05, \eta_p^2 = .11$, Strength $F(1,35) = 46.89, p < .0001, \eta_p^2 = .57$, and the interaction List*Strength $F(1,35) = 19.41, p < .0001, \eta_p^2 = .36$. The Bayesian ANOVA included similar variables: Attention + List + Strength + List*Strength (BF$_{10}$ = 2.00e23). The analysis of effects produced Bayesian inclusion factors with strong evidence for Attention (BF$_{inclusion}$ = $\infty$), List (BF$_{inclusion}$ = 9.81), Strength (BF$_{inclusion}$ = 2.39e7), and List*Strength (BF$_{inclusion}$ = 34.49).

Table 16. Exp 5: Correct Recall

<table>
<thead>
<tr>
<th>A) List</th>
<th>Strength</th>
<th>Attention</th>
<th>Mean</th>
<th>SEM</th>
<th>Mean</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Pure</td>
<td>Weak</td>
<td>0.38</td>
<td>0.04</td>
<td>0.20</td>
<td>0.02</td>
</tr>
<tr>
<td>36</td>
<td>Mixed</td>
<td>Strong</td>
<td>0.42</td>
<td>0.03</td>
<td>0.25</td>
<td>0.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B) List</th>
<th>Strength</th>
<th>Attention</th>
<th>Mean</th>
<th>SEM</th>
<th>Mean</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Pure</td>
<td>Weak</td>
<td>0.39</td>
<td>0.03</td>
<td>0.19</td>
<td>0.02</td>
</tr>
<tr>
<td>36</td>
<td>Mixed</td>
<td>Strong</td>
<td>0.45</td>
<td>0.03</td>
<td>0.21</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Note: Proportion of words correctly recalled reported with standard error of the mean.

Figure 38. Exp 5 Correct Recall

Note: A) Easy B) Hard
In the hard condition (Figure 38B), there were main effects of Attention $F(1,35) = 126.56, p < .0001, \eta^2_p = .78$, Strength $F(1,35) = 35.75, p < .0001, \eta^2_p = .51$, and two interactions Attention*Strength $F(1,35) = 7.12, p = .01, \eta^2_p = .03$ and List*Strength $F(1,35) = 10.03, p < .01, \eta^2_p = .22$. These conditions were also included in the most credible model: Attention + List + Strength + List*Strength, BF$_{10} = 1.74e^{40}$. The accompanying analysis of effects showed evidence for including Attention (BF$_{inclusion} = \infty$), List (BF$_{inclusion} = 1.18$), Strength (BF$_{inclusion} = 6.37e^5$), and List*Strength (BF$_{inclusion} = 5.34$). Considering the drastic difference in the BF$_{inclusion}$ for the interaction (and to include the interaction, the variable List must be included), the model without the interaction (Attention + Strength) was the second most probable model however, error jumped drastically from 3.57% to 36.97%.

Experiment 5 purpose was to investigate whether contextual accumulation in a single trace is disrupted in the DA conditions. Sahakyan and Malmberg (2018) determined the null and slightly negative LSEs found from the free recall tests in the DA condition were the result of multiple weak traces representing words that were studied multiple times. However, the positive LSEs found in the DA conditions in Experiment 3 suggested that accumulation of context may still be occurring but affecting word traces differently depending on how long they were studied. In both easy and hard FA conditions in the current experiment, there was an expected strong positive LSE. Dividing attention did reduce overall recall compared to the FA counterpart, however positive LSEs patterns were still present. In the hard condition, dividing attention produced a positive LSE pattern that was more condensed than the pattern seen in the full attention condition. In easy condition, strong words were better recalled in mixed than pure lists, but weak words were recalled equally in both mixed and pure lists. Interestingly again, there was no difference statistically between Difficulty in recall for DA.

**Serial Position**

The serial position graphs below display the easy condition in the left column and the hard condition and are separated by pure lists (Figure 39) and mixed lists (Figure 40). Recall across positions in the FA condition appeared to be slightly higher on earlier list items for both pure and mixed lists with an exception for recall in hard mixed weak lists, where later items had distinctly better recall. Recall across serial positions was reduced in the DA conditions, however the added cognitive load seemed to not affect recall in any specific positions across lists. A Difficulty (easy vs. hard) x List (pure vs. mixed) x Strength (weak vs. strong) x Position Binned (1-6 vs. 7-14 vs. 15-20) mixed ANOVA was conducted with difficulty as the only between-subjects factor to investigate difference
between DA difficulties. Comparing the easy and hard DA condition revealed no difference between Difficulty \((p = .10)\), but there were main effects of List \(F(1,70) = 3.94, p = .05\), Strength \(F(1,70) = 34.98, p < .0001, \eta^2 = .02\), Position \(F(1,90, 132.74) = 3.25, p = .04\), and the interaction List*Strength \(F(1,70) = 7.64, p < .01\).

Attention \((2) \times \text{List} (2) \times \text{Strength} (2) \times \text{Position} \text{Binned} (3)\) repeated-measure ANOVAs were also conducted for both Difficulty conditions separately. In the easy condition, there were main effects of Attention \(F(1,35) = 53.27, p < .0001, \eta^2 = .60\), Strength \(F(1,35) = 43.91, p < .0001, \eta^2 = .56\), Position \(F(1.80, 62.92) = 12.78, p < .0001, \eta^2 = .27\), and two interactions List*Strength \(F(1,35) = 25.48, p < .0001, \eta^2 = .42\) and Attention*Position \(F(1.74, 60.84) = 5.00, p = .01, \eta^2 = .60\).

For the hard condition, there were main effects of Attention \(F(1,35) = 107.87, p < .0001, \eta^2 = .76\), Strength \(F(1,35) = 29.59, p < .0001, \eta^2 = .46\), Position \(F(1.56, 54.73) = 9.41, p < .001, \eta^2 = .21\). Additionally, there were four interactions including: List*Strength \(F(1,35) = 22.17, p < .0001, \eta^2 = .39\), Attention*Position \(F(1.82, 63.87) = 7.62, p < .01, \eta^2 = .18\), Attention*List*Position \(F(1.83, 64.19) = 9.44, p < .001, \eta^2 = .21\), and Attention*Strength*Position \(F(1.73, 68.46) = 4.02, p = .03, \eta^2 = .10\).

Pure weak words that were studied once for 6 s showed a strong tendency to recall earlier positions than strong words that were studied six times for 1 s in the FA condition. This tendency for recall of earlier list positions was not present in the DA in pure lists. Additionally, the increase in difficulty of the divided attention task did not appear to change outcomes that were produced in the easy condition.
First Recall Probability

First Recall Probability (FRP) for Experiment 5 are plotted in Figure 41 for pure lists and Figure 42 for mixed lists. The x-axis shows the first and second positions, while subsequent positions are binned by two. The probability to recall initially studied words was prominent across lists. Since word lists were studied in halves, the occasional increase in probability around positions 11 to 12 is unsurprising given the start of studying the second half of the list. In pure lists (Figure 41), the primacy effect was strongest in FA pure weak compared to pure strong lists. The first recall probability was reduced in the DA condition compared to the FA lists. However, increasing difficulty in the DA tasks did not fully exacerbate this trend.

Figure 40. Exp 5 Mixed Lists Serial Position
Note: Position correspond to the respective position of a unique word when first studied on each list. Each list has 20 unique words. For example, position 1-6 displays the binned average for the first 6 words studied.

First Recall Probability

Figure 41. Exp 5 Pure Lists First Recall Probability
Note: Position corresponds to the respective position of a unique word when first encountered on each list. Each list has 20 unique words. For example, position 11-12 displays the binned average for the 11th and 12th unique word.
A mixed ANOVA comparing easy and hard DA show a significant main effect only for Position $F(2, 140.09) = 28.01, p < .0001, \eta^2 = .07$. Difficulty was not significant ($p = .35$) indicating that increasing the difficulty of the digit monitoring task had little effect on FRP in the divided attention conditions.

In the easy condition, there was a main effect of Attention $F(1,35) = 21.46, p < .0001, \eta^2 = .38$, Position $F(1.52, 53.17) = 59.30, p < .0001, \eta^2 = .63$, and the interactions List*Strength $F(1, 35) = 11.15, p < .01, \eta^2 = .24$ and Attention*Position $F(1.56, 54.58) = 15.10, p < .0001, \eta^2 = .30$. Analysis of the hard condition produced main effects of Attention $F(1, 35) = 4.79, p = .04, \eta^2 = .12$, Position $F(1.43, 49.92) = 37.67, p < .0001, \eta^2 = .52$, and the interaction Attention*Position $F(1.78, 62.35) = 7.44, p < .01, \eta^2 = .18$.

![Graphs showing recall probability for easy and hard conditions](image)

**Figure 42.** Exp 5 Mixed Lists First Recall Probability

*Note: Positions correspond to the respective position of a new word when first encountered for each list. Each list has 20 unique words. For example, position 11-12 displays the binned average for the 11th and 12th unique word.*

### Conditional Recall Probability

Conditional Recall Probability (CRP) curves for pure lists (Figure 43) and mixed lists (Figure 44) are plotted below. Additionally, Figure 45 displays recall from mixed lists without separating word strength. Both pure and mixed lists in the FA condition showed strong forward trends in recall which is shown by a higher probability peak in the positive +1 lag and a steep curve towards the positive positions. In contrast, the probability of recalling items in the forward direction was reduced in both easy and hard DA conditions. All DA conditions in Experiment 5 showed reduced probabilities for forward lag and often approached probabilities similar to the negative lags indicating recall was likely in either direction and not motivated by interitem associations.
A mixed effects ANOVA for conditional recall probabilities was conducted to compare the easy and hard DA conditions. There were main effects of Difficulty, $F(1,70) = 7.19, p < .01$, Strength $F(1,70) = 8.19, p < .01$, Lag $F(4.22, 295.25) = 26.80, p < .0001, \eta_p^2 = .08$, and one interaction of Strength*Lag $F(4.58, 320.67) = 3.75, p < .01$.

To analyze each Difficulty condition, repeated measures ANOVAs were conducted. In the easy condition, there was a main effect of Attention $F(1,35) = 13.18, p < .001, \eta_p^2 = .27$, Strength $F(1,35) = 6.29, p = .02, \eta_p^2 = .15$, Lag $F(2.29, 80.26) = 40.11, p < .0001, \eta_p^2 = 0.53$, Attention*Lag $F(2.66,93.22) = 7.31, p < .0001, \eta_p^2 = .17$, and Strength*Lag $F(3.09, 107.99) = 2.79, p = .04, \eta_p^2 = 0.07$. Similarly, the hard condition ANOVA produced similar results, including main effects of Attention $F(1,35) = 69.98, p < .0001, \eta_p^2 = .67$, Strength $F(1,35) = 15.90, p < .001, \eta_p^2 = .31$, Lag $F(2.77,97.11) = 56.82, p < .001, \eta_p^2 = 0.62$, Attention*Lag $F(2.82, 98.81) = 12.18, p < .001, \eta_p^2 = .17$.

Figure 44. Exp 5 Pure Lists Conditional Recall Probability

*Note:* A lag of 1 represents recalling the word presented for study immediately after the word just recalled. DO CRP curves were calculated using the respective positions for words corresponding to the first order studied.

Figure 43. Exp 5 Mixed Lists Conditional Recall Probability

*Note:* A lag of 1 represents recalling the word presented for study immediately after the word just recalled. DO CRP curves were calculated using the respective positions for words corresponding to the first order studied.
.26, and Strength*Lag \( F(3.88,135.63) = 2.44, p = .05, \eta^2_p = .07 \). CRP curves in the easy and hard conditions produced similar results, which matches the similarities in DA curves across both pure and mixed lists.

![Figure 45. Exp 5 Combined Mixed Lists Conditional Recall Probability](image)

**Experiment 5 Conclusions**

The goal of Experiment 5 was to exploit the differences between word trace accumulation to determine if increasing cognitive load during study disrupts trace accumulation. Sahakyan and Malmberg (2018) concluded that the null LSE found in the DA condition was due to multiple weak traces representing a word that was studied many times rather than a singular information-rich trace. Experiment 5 had two DA manipulations, an easy condition (listening task at a rate of 2 s per number) and a hard condition (listening task at a rate of 1 s per number) and in both conditions, positive LSE patterns were present. The current Experiment 5 results along with the results from Experiment 3 indicate that accumulation of context may still occur in the DA conditions, but word traces are affected differently depending on how long a word was studied.

In the current experiment, words were either studied briefly but repetitively (strong, 6 attempts 1 s each) or in a long continuous manner (weak, 1 attempt, 6 s each). There were strong +LSE in the FA conditions, showing a pattern where better sampling of strong words in mixed lists and better recall of weak words on pure lists occurs. This pattern of recall indicates that strong words had more accurate contextual information due to the higher rate of sampling in mixed lists and pure weak words sustained less interference than pure strong (Shiffrin, Radcliff, & Clark, 1990).

Dividing attention did reduce overall recall in comparison, however positive LSE patterns were less distinct but still present. This may occur through either creating new weak traces in each study attempt (Sahakyan & Malmberg, 2018) or by storing additional noise to traces (i.e., storing relevant information with irrelevant...
information), thus making contextual information more variable and degrading its overall later utility. Since attention in the easy condition was likely diverted every 2 s to listen for the next digit, this would affect weak words more than strong. This pattern of diversion would allow for better storage of strong words (which were shown for 1 s) than weak (6 s), which could explain the large difference between DA recall of strong and weak mixed words as well as the potential interference among pure strong traces preventing better recall. Additionally, if the easy condition created more trouble for weak words than strong, then this might explain the lack of difference between mixed weak and pure weak word recall. In the hard condition, dividing attention still produced a positive LSE pattern, but the mean differences between list and strength were more condensed within list types and less drastic between strengths than the pattern seen in the FA conditions.

Interestingly, increasing the speed of the digit monitoring task did not drastically affect later correct recall performance. The differences between the DA Difficulty conditions are best observed in the mixed lists CRP curves. The forward asymmetrical curve in the DA strong words in the easy mixed lists (dotted line bottom left, Figure 44) show better evidence of utilizing interitem information while this effect was almost absent in the easy mixed weak lists (dotted line, top left, Figure 44). In contrast, the hard DA weak and strong mixed lists show little utilization of interitem associations in any forward lag (dotted lines, right column, Figure 44), indicating both word strengths were equally affected. This conclusion is further supported by the differences in DA recall between Difficulty in the combined CRP curves (Figure 45). The easy DA still maintains a slight positive lag asymmetry, whereas the hard condition curve CRP positive and negative lags are close to symmetrical.

It is still possible that even the faster listening task was still not difficult enough to disrupt trace accumulation. As stated in the conclusions for Experiment 4, the Sahakyan & Malmberg (2018) free recall experiment included another ‘task’ for the participants to perform during study. Rather than just listening for numbers and studying words on the screen, they were to judge each word on how ‘pleasant’ they found it by selecting a rating on the screen within the time frame of study. Considering the hard condition produced a less distinct +LSE, it is possible that further cognitive strain would exacerbate this collapse.
Chapter Nine:

Experiment 6

Experiment 6 is based off a small set of data collection, where an additional condition was added into the mixed-pure design. In this design, the conditions included another type of mixed list intended to counterbalance the study time in blocked lists. For example, typical 20-word block-mixed lists used in Experiment 2 were blocked by word strength, where half of the words are studied first in one strength (i.e., weak, 1-10, repeated 3 times) and then the second half of the list is studied in the second strength (i.e., strong 11-20, repeated 3 times). A second mixed list would also be presented with strong words first and weak words second. An example of the mixed list from Experiment 2 is shown in the top section of Table 17. The addition of counterbalanced intramixed list (shown in the bottom section of Table 17) was to include a condition with which strengths of words were mixed within each half of the list. The intramix lists still presented words three times in the same order (and the same lag of 9 words), but instead of blocking strong and weak words, weak and strong items were mixed within the whole list. The intramix DO also mixed word strengths with each repetition following the different order pattern from Experiment 2. A representation of the DO lists used can be viewed in Table A1.

Table 17. Same Order Block-Mixed and Intramixed Lists

<table>
<thead>
<tr>
<th>Strength Blocked</th>
<th>Order</th>
<th>3 reps of 1-10</th>
<th>3 reps of 11-20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Word Position</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>ML13</td>
<td>1 s</td>
<td>3 s</td>
<td></td>
</tr>
<tr>
<td>ML31</td>
<td>3 s</td>
<td>1 s</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intramixed Strength</th>
<th>Order</th>
<th>3 reps of 1-10</th>
<th>3 reps of 11-20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Word Position</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>ML NB1</td>
<td>1 s</td>
<td>3 s</td>
<td>3 s</td>
</tr>
<tr>
<td>ML NB2</td>
<td>3 s</td>
<td>1 s</td>
<td>3 s</td>
</tr>
</tbody>
</table>
lists from Experiment 2) and the correct recall graphs from Experiment 2 same order (Figure 12) are presented alongside for easy comparison.

Interestingly, when study time was mixed equally within half the list, a negative LSE emerged both in FA and DA as compared to the null LSE and slight +LSE produced from the Experiment 2 SO conditions. Further investigation into these effects was done by plotting both mixed list types against each other in the same graph, separated by word strength in Figure 47.

When comparing the two mixed designs, the FA and DA conditions appear to produce a reversal of each other. Lists that were blocked (black line) show a larger difference between the probability of recall for word strengths in both attention conditions. However, mixing the word strengths (dotted line) across positions appeared to moderate this effect by increasing recall of weak words and reducing recall for strong, as well as tempering the difference in recall between full and divided attention.
Figure 48 plots both intramixed and block-mixed lists from Experiment 2. The block-mixed lists are graphed with both strong and weak words (rather than splitting plots by word strength). Experiment 2 Block-Mixed lists are shown in Figure 48A and the intramixed lists are plotted in Figure 48B.

When comparing the two mixed list designs, they appear very similar to each with the exception of a steeper slope from lag +1 to +2 in the intramixed design. The reliance on lag +2 and +3 forward from the study position in the blocked design shows higher probabilities than in the FA intramix design, while the DA slopes appear similar in both graphs. Additionally, serial positions are shown as scatter plots below for intramixed and blocked lists (Figure 49) below. The solid dots in the scatter plots represent strong words, while stars represent weak words. Larger versions of these plots and the DO condition graphs are also available in Appendix A.

The serial position graphs of intramixed lists reveals removal of the strong preferential effects for strong words, and thus there was a less consistent reduction in weak words. Primacy effects appeared to disappear in the
full attention conditions. The differences produced between the block-mixed and the intramixed list may lie in how participants allocate attention to each item as they study. By changing the study time for each word but maintaining order, the predictability for the duration each word is removed. If so, that may also explain why the effects typically shown in the DA condition were more moderate in the intramixed lists. In a study testing pupillometry, attention, and word lists, Unsworth and Miller (2021) found evidence that when list length was unknown, participant’s allocated attention to early list positions, whereas pupil dilation decreased (or allocated attention decreased) as the study list continued. Increased attention in early list positions can describe the primacy effect, as more resources are being directed. Additionally, when word presentation was short (2 s), a dilation of the pupil occurred early during encoding but constricted as study time continued, indicating that attention was initially allocated and then followed by habituation (Unsworth & Miller, 2021; Phaf & Wolters, 1993). If attention wanes as predictability/monotony of study increases, pure lists and block-mixed lists may be subjected to increased attentional waning and issues. Yet if predictability of study is reduced, habituation or boredom in the participant during study might be avoided to an extent allowing for a better look at the encoding process.

**Experiment 6 Methods**

**Participants**

Forty-six undergraduate University of South Florida students signed up to participate via the SONA system. They were compensated with course credit for their participation. Six participants were dropped from inclusion in the analysis due to technical error with the program, failing to understand the task, or not meeting the minimum performance (75%) in the divided attention task. This left 40 participants in the total experiment.

**Design**

A modified mixed-pure design was presented, with mixed lists in the intramixed strength compositions. Strength was manipulated by study time, with strong words presented for 3 s and weak for 1 s. All words were spaced in study at a lag of nine words, and words were repeated three times. There were two order conditions, same order (SO) which repeated order of study or Different Order (DO), which presented words in the following order: 1-
Table 18. Exp 6 Same Order List Layout

<table>
<thead>
<tr>
<th>Version 1</th>
<th>Repeat 3x</th>
<th>Same Order</th>
<th>Repeat 3x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>s w w s s w s w s w</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: *S* = strong word (3 s), *W* = weak word (1 s)

<table>
<thead>
<tr>
<th>Version 2</th>
<th>Repeat 3x</th>
<th>Repeat 3x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20</td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>w s s w w s w s w s w</td>
<td></td>
</tr>
</tbody>
</table>

Table 19. Exp 6 Different Order List Layout

<table>
<thead>
<tr>
<th>Version 1</th>
<th>Present 1x</th>
<th>Present 1x</th>
<th>Present 1x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>s w w s s w s s w s w</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Version 2</th>
<th>Present 1x</th>
<th>Present 1x</th>
<th>Present 1x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>w s s w s s w s s w s w</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Materials

Materials were the same as used in Experiment 4.

Procedure

The procedure was the same as in Experiment 4.

Experiment 6 Results

In all subsections of the results for Experiment 6 (except correct recall), the graphs show the same order (SO) condition in the left column and the Different Order (DO) condition in the right column. Weak words are shown in the first row, while strong words are shown in the second row. Position and Lag variables violated sphericity, so Greenhouse-Geisser adjusted values are used when appropriate. Error rates for the Bayesian models were all below 6%.
Correct Recall

Results for the probability of correct recall in Experiment 6 for the SO (Figure 50A and Table 20A) and DO (Figure 50B and Table 20B) conditions are presented below.

**Table 20. Exp 6 correct recall**

*Note: A) SO B) DO*

<table>
<thead>
<tr>
<th>List</th>
<th>Strength</th>
<th>Attention</th>
<th>Full</th>
<th>SEM</th>
<th>Divided</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure</td>
<td>Weak</td>
<td>Mean</td>
<td>0.35</td>
<td>0.02</td>
<td>0.17</td>
<td>0.02</td>
</tr>
<tr>
<td>40</td>
<td>IntraMix</td>
<td>Strong</td>
<td>0.51</td>
<td>0.03</td>
<td>0.28</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>0.42</td>
<td>0.02</td>
<td>0.20</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SEM</td>
<td>0.43</td>
<td>0.02</td>
<td>0.28</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Figure 50. Exp 6 Correct Recall**

*Note: A) SO B) DO*

In Figure 50A and 50B, the full attention (FA) condition is on the left and divided attention (DA) is on the right. An Order (2) x Attention (2) x List (2) x Strength (2) mixed ANOVA was conducted with Order as the only between-subjects condition. Order was not a significant main effect \( (p = .18) \) indicating there was little difference between overall recall between these conditions. There was a significant main effect of Attention \( F(1,78) = 152.59, p < .0001, \eta_p^2 = .66 \), and across both conditions, and dividing attention reduced overall recall compared to the FA condition. Word strength was also significant Strength \( F(1,78) = 106.19, p < .0001, \eta_p^2 = .58 \), indicating that the increase in study time was an effective strengthener, even when both weak and strong words were repeated thrice. The interaction List*Strength \( F(1, 78) = 57.24, \eta_p^2 = .42 \) was also significant. The interaction describes the negative LSE where strong words were better recalled on pure lists and weak words were better recalled on mixed lists. The most credible model produced in the Bayesian ANOVA included Attention + List + Strength + List*Strength (BF\( _{10} \))
with the analysis of effects showing strong evidence for including: Attention ($\text{BF}_{\text{inclusion}} = 1.07e^{13}$), List ($\text{BF}_{\text{inclusion}} = 1.38e^{6}$), Strength ($\text{BF}_{\text{inclusion}} = 1.07e^{13}$), and List*Strength ($\text{BF}_{\text{inclusion}} = 8.91e^{6}$).

In the SO condition (Figure 50A), there were main effects of Attention $F(1,39) = 72.96, p < .0001, \eta^2_p = .65$, Strength $F(1,39) = 55.82, p < .0001, \eta^2_p = .59$, and the interaction List*Strength $F(1,39) = 17.91, p < .001, \eta^2_p = .31$. Similarly, the most credible Bayesian ANOVA model included Attention + List + Strength + List*Strength ($\text{BF}_{10} = 3.81e^{31}$). The analysis of effects for the models considered were Attention ($\text{BF}_{\text{inclusion}} = \infty$), List ($\text{BF}_{\text{inclusion}} = 49.07$), Strength ($\text{BF}_{\text{inclusion}} = 3.44e^{6}$), and List*Strength ($\text{BF}_{\text{inclusion}} = 209.24$).

There were similar results in the DO condition (Figure 50B) including Attention $F(1,39) = 80.69, p < .0001, \eta^2_p = .67$, Strength $F(1,39) = 50.61, p < .0001, \eta^2_p = .56$, and Attention*Strength $F(1,39) = 51.03, p < .0001, \eta^2_p = .57$. The Bayesian model included the same variables, Attention + List + Strength + List*Strength ($\text{BF}_{10} = 3.03e^{33}$), with strong inclusion factors for each: Attention ($\text{BF}_{\text{inclusion}} = 3.22e^{14}$), List ($\text{BF}_{\text{inclusion}} = 1707.92$), Strength ($\text{BF}_{\text{inclusion}} = 6.73e^{8}$), and List*Strength ($\text{BF}_{\text{inclusion}} = 9021.23$).

These results show strong negative LSEs across conditions, which was likely achieved from modifying the typical mixed list from blocking to intramixing word strength. Normally, a mixed lists contains half weak and half strong words, presented with either the weak words in first half and then strong second or vice versa. Essentially this seems to create two mini lists that are studied together, rather than truly mixing the word strengths within the list. Instead, Experiment 6 presented mixed lists that evenly spread weak and strong words across the mixed lists. Whereas the traditional mixed lists are known to produced positive or null LSEs in free recall (depending on the strengthener used), the current presentation appeared to deviate from the typical recall patterns. This pattern was present in both order conditions and remained present in divided attention conditions.

**Serial Position**

Serial position curves are plotted below for pure (Figure 51) and mixed lists (Figure 52). Positions were binned to show general trends in recall across positions. Recall across positions tended to be relatively stable, with occasional minor decreases in the middle positions. There was not a significant difference between SO and DO groups ($p = .19$). Attention was a main $F(1,78) = 149.78, p < .0001, \eta^2_p = .66$, which can be seen by the general negative shift in recall across positions in the DA conditions. Additionally, Strength $F(1,78) = 73.65, p < .0001, \eta^2_p$
= .49, Position $F(1.65,128.55) = 8.14, p < .01, \eta_p^2 = .09$, and two interactions List*Strength $F(1,39) = 67.41, p < .0001, \eta_p^2 = .46$ and Attention*List*Strength $F(1,78) = 5.71, p < .01, \eta_p^2 = .07$ were also significant main effects.

In the SO condition, there were main effects for Attention $F(1,39) = 69.84, p < .0001, \eta_p^2 = .64$, Strength $F(1,39) = 28.26, p < .0001, \eta_p^2 = .42$, List*Strength $F(1,39) = 26.07, p < .0001, \eta_p^2 = .40$, and Attention*List*Strength $F(1,39) = 4.60, p = .04, \eta_p^2 = .11$. The most credible Bayesian model included Attention + List + Strength + List*Strength ($BF_{10} = 8.13e^{34}$) with the analysis of effects showing strongest inclusion probabilities for Attention ($BF_{inclusion} = \infty$), List ($BF_{inclusion} = 157.53$), Strength ($BF_{inclusion} = 2.11e^5$), and List*Strength ($BF_{inclusion} = 958.69$).
The DO condition had main effects for Attention $F(1,39) = 81.75, p < .0001, \eta^2_p = .68$, Strength $F(1,39) = 48.27, p < .0001, \eta^2_p = .55$, Position $F(1.62,63.15) = 6.01, p < .01, \eta^2_p = .13$, and the interaction List*Strength $F(1,39) = 48.71, p < .0001, \eta^2_p = .56$. Additionally, the most credible Bayesian model included Attention + List + Strength + Position + List*Strength ($BF_{10} = 4.18e^{45}$). The corresponding analysis of effects showed strongest probabilities to include Attention ($BF_{inclusion} = 7.23e^{13}$), List ($BF_{inclusion} = 1512.37$), Strength ($BF_{inclusion} = 6.19e^{9}$), Position ($BF_{inclusion} = 40.60$), and List*Strength ($BF_{inclusion} = 1.06e^{5}$).

Recall across positions did not differ between the Order conditions indicating that mixing word strengths within the list appeared to mitigate the effects of preventing interitem associations to strengthen. Figure 53 compares mixed lists from Experiment 4 and Experiment 6 which reveals some interesting patterns. There appeared to be little effect of recall across positions in the DA conditions for SO and DO lists. In the FA conditions recall for weak words increased while recall for strong words decreased when words were intramixed rather than blocked. These patterns are indicative of the negative LSE seen in correct recall (Figure 50).

**First Recall Probability**

First recall probability (FRP) is plotted for pure (Figure 54) and mixed (Figure 55) lists. The lists were binned by two positions (except for position 1 and 2) for better clarity across positions. In pure lists (Figure 54)
weak words did not have a strong primacy effect in either full or divided attention condition. Primacy for pure strong lists were slightly higher than in the weak lists, and oddly the DA condition was stronger in the position 1 than the FA condition in SO strong lists. FRP for early positions were more distinct in the mixed lists (Figure 55). While FA conditions showed a greater tendency for primacy across all mixed lists, the differences in the DA condition were not large. Even with a varying study order, the DO conditions still showed primacy for the first word studied.

Figure 54. Exp 6 Pure Lists First Recall Probability
*Note: DO serial position curves show the first order studied.*

Comparing order effects, the main effect of Order was not significant ($p = .96$) indicating that order repetition did not significantly affect FRPs. There was a small effect of Attention $F(1,78) = 5.87, p = .02, \eta^2_p = .07$ and an effect of Position $F(1,73, 134.87) = 33.25, p < .0001, \eta^2_p = .30$ showing a small but significant increase in FRP for full attention and large preferences for the first position across lists. The only main effect in the SO condition was an effect of Position $F(1.46, 57.06) = 18.17, p < .0001, \eta^2_p = .32$ (Bayesian model: Position, $BF_{10} = 4.92e^{22}, BF_{\text{inclusion}} = \infty$), while the DO condition showed main effects for Attention $F(1,39) = 6.13, p = .02, \eta^2_p = .14$

Figure 55. Exp 6 Intramixed Lists First Recall Probability
*Note: DO serial position curves show the first order studied.*
and Position $F(2.05, 79.87) = 15.93, p < .0001, \eta^2_p = .29$. The most credible model from the Bayesian ANOVA for the DO condition included only Position ($BF_{10} = 1.24e^{14}, BF_{inclusion} = 1.19e^{13}$).

**Conditional Recall Probability**

The conditional recall probability (CRP) curves are plotted for pure (Figure 56), mixed (Figure 57), and combined mixed lists (Figure 58). Figure 58 depicts recall of both strong and weak words rather than separating the graph to display the CRPs for only weak or strong words. The CRP data analyzed only positions -2 through +2 to reduce complexity of the models for computing purposes.

In the SO conditions, there were asymmetrical strong forward CRP curves in the FA conditions. Pure weak and strong lists showed similar peaks in the +1 lag (Figure 56), and the weak and strong words had comparable +1 lag in the mixed lists (Figure 57). The DA condition drastically reduced the tendency to recall adjacently studied words in the SO condition, with the strongest difference in the pure weak lists, where recalling in the reverse order was more probable. In SO mixed lists, the DA condition reduced these CRP curves to an almost symmetrical pattern, indicating that recall in either direction was equally probable. DO CRP curves were relatively flat and symmetrical which is expected if interitem associations never had a chance to strengthen. There were slight tendencies for forward recall in the FA condition, but forward CRPs flattened out in the DA conditions. When CRP for mixed lists was considered as a whole (Figure 58), rather than shown by word strength, no new patterns emerged.

There was a main effect of Order $F(1,78) = 19.87, p < .0001, \eta^2_p = .20$, Attention $F(1,78) = 57.78, p < .0001, \eta^2_p = .43$, Attention*Order $F(1,78) = 7.22, p < .001, \eta^2_p = .08$, List $F(1,78) = 15.83, p < .001, \eta^2_p = .17$, Strength $F(1,78) = 7.41, p < .01, \eta^2_p = .09$, Lag $F(1.71,133.22) = 41.73, p < .0001, \eta^2_p = .35$, Lag*Order $F(1.71,133.22) = 10.02, p < .001, \eta^2_p = .11$, Attention*Lag $F(2,155.73) = 16.23, p < .0001, \eta^2_p = .17$, and Attention*Lag*Order $F(2,155.73) = 4.84, p < .01, \eta^2_p = .06$. 

102
The SO condition had main effects of Attention $F(1,39) = 40.70, p < .0001, \eta^2_p = .51$, List $F(1,39) = 14.89, p < .0001, \eta^2_p = .28$, Strength $F(1,39) = 4.92, p = .003, \eta^2_p = .11$, Lag $F(1.52, 59.23) = 30.84, p < .0001, \eta^2_p = .44$, Attention*Lag $F(1.75, 68.19) = 15.28, p < .0001, \eta^2_p = .28$, and Attention*Strength*Lag $F(2.48, 96.85) = 4.91, p < .01, \eta^2_p = .11$. The Bayesian ANOVA yielded a much less convoluted model, including Attention + List + Lag + Attention*Lag ($BF_{10} = 1.63e^{47}$). The analysis of effects for the variables in this model included Attention ($BF_{\text{inclusion}} = 2.74e^{12}$), List ($BF_{\text{inclusion}} = 0.69$, with a probability of including the variable given the data 0.84), Lag ($BF_{\text{inclusion}} = \infty$), and Attention*Lag ($BF_{\text{inclusion}} = 5.41e^{7}$).

![Figure 56. Exp 6 Pure Lists Conditional Recall Probability](image1.jpg)

Note: A lag of 1 represents recalling the word presented for study immediately after the word just recalled. DO CRP curves were calculated using the respective positions for words corresponding to the first order studied in each list when the word was first encountered.

![Figure 57. Exp 6 Intramixed Lists Conditional Recall Probability](image2.jpg)

Note: A lag of 1 represents recalling the word presented for study immediately after the word just recalled. DO CRP curves were calculated using the respective positions for words corresponding to the first order studied in each list when the word was first encountered.
In contrast, the only main effects in the DO condition were Attention $F(1,39) = 17.26, p < .001, \eta^2_p = .31$ and Lag $F(1.52,59.23) = 30.84, p < .0001, \eta^2_p = .44$. The most credible Bayesian ANOVA included Attention + Lag ($BF_{10} = 4.38e^7$) with strongest effects from variables Attention ($BF_{inclusion} = 7.20$) and Lag ($BF_{inclusion} = 2.3e^5$).

In general, the FA CRP curves are similar to the CRP curves in Experiment 4. The only difference between these experiments was the composition of the mixed lists, which did not appear to affect the CRP curves but did produce drastically different free recall outcomes.

**Figure 58.** Exp 6 Combined Intramixed Lists Conditional Recall Probability

**Experiment 6 Conclusions**

The small modification of the structure of mixed lists in the mixed-pure paradigm in Experiment 6 showed prominent negative LSEs in the full and divided attention conditions in both Order conditions. Experiment 2 and 4 block-mixed lists (or chunked via the time strengthener) created two smaller pure lists and were presented consecutively. Alternatively, Experiment 6 changed only the construction of the mixed lists by interlacing the strengtheners throughout the entire list. Implementing this presentation produced negative LSEs from free recall, whereas blocking mixed lists in Experiments 2 and 4 produced null LSEs.

The intramixed lists did not cause many drastic changes in the other recall measures. Serial position curves did not differ between Order conditions, indicating that mixing word strengths may have potentially mitigated any effects of differing the order of study across multiple study attempts. FRP data also did not differ between Order conditions besides Position, while other variables appeared to have little effect across lists. Comparing the combined strength mixed lists between Experiment 4 and 6 showed only minor differences in the magnitudes of +1 lag in both FA and DA conditions.

A negative LSE describes a pattern where mixed weak words are recalled better than pure weak and pure strong are recalled better than mixed strong. This pattern is opposite of what typically occurs in free recall, which
also indicates a different pattern of trace strengthening is likely occurring in the current experiment. The current correct recall results show that mixed weak items were slightly boosted at the expense of mixed strong words, with the same pattern repeated in the DA conditions. Typically, strong words interfere with weak words on mixed lists ultimately impairing the recall of weak words, yet mixed words in the current experiment appear to lack this effect of interference. During study in Experiment 6, participants are less likely to be able to detect patterns in displayed study time affecting any initial strategic planning or attentional waning that may occur when patterns become obvious. With attention being reallocated to the words on screen to study, the unpredictable timing may create more distinct context to store from each study attempt. Although the information stored is still unequal between word strengths, the repetition allows for gradual trace accumulation. This lack of detectable rhythm or pattern in study may redirect attention in a way that creates distinct context in strong traces that boost or lend context to weaker items, which will be discussed further in detail in the General Discussion.
Chapter Ten:  

General Discussion

After the results of Experiments 4, 5, and 6 were analyzed, I decided to take a second look at the replication of the Sahakyan and Malmberg (2018) experiment. The serial, FRP, and CRP data is graphed below (Figure 59, 60, and 61 respectively) and these analyses were not investigated in the original experiment. The most noticeable difference in these graphs are the distinct difference in the FRP (Figure 60) and CRP (Figure 61) graphs between full and divided attention. When words were spaced twice and attention was divided, it appears that the utilization of initially stored context was lost (no distinct FRPs in strong words). Additionally, the CRPs were oddly flat, indicating the lack of utilization of item-context and interitem associations also was drastically different than in Experiment 4, 5 and 6. These very shallow slopes may indicate that retrieval was guided by single word recall and not often with the cue combination of context and the previously recalled word.

![Figure 59. Replication Serial Position](image)

These results bolster the argument that strong traces are no longer being strengthened when attention is divided in the Sahakyan and Malmberg (2018) experiment. When an item was massed, there was a long but single attempt (12 s in total) to store relevant information in the trace. The shorter duration of study for strong words (6 s separated twice) meant that there would be two attempts to store and accrue context and item information. In addition, Sahakyan and Malmberg (2018) also included a deep processing task concurrent during study, requiring subjects to rate each word on its ‘pleasantness’. The DA task should have added additional cognitive load to the
study and rating tasks, so it’s possible that a single study attempt for strong words may have been accidentally missed (due to switching being the rating task and DA task), rendering the first or second storage attempt small or lost, leaving the single study trial to represent the strong trace. Alternatively, the DA condition may have created an environment with such a high cognitive load that remembering there was a first study attempt was lost or the trace was not retrievable to the STS, and instead a second independent trace was stored representing a single study attempt. Since the strong FRPs in the FA condition for strong versus weak mixed words indicates the presence of trace interference, the correct recall and other analyses do seem to describe situations where trace interference is present (FA condition) and when trace interference is lacking (DA condition).

Strengthening context occurs through spacing items in study, but depending on the task, the number of repetitions that occurs is most important. Sahakyan and Malmberg (2018) spaced items twice which gave strong words only two attempts to potentially accrue contextual information. In contrast, Experiment 4 spaced all words three times and although weak words were presented very briefly (1 s), three separate storage attempts were enough to strengthen traces. Adding in cognitive load in the DA condition did disrupt overall recall, but the repetition of study seemed to protect words from missed storage attempts. Experiment 5 was similar to Sahakyan & Malmberg (2018) in that weak words were massed and strong spaced. However, weak words were massed once for a total of 6 seconds (rather than 12 s) and strong words were spaced 6 times for 1 s. The correct recall graphs were very different, in that there was a negative LSE in DA condition from Sahakyan and Malmberg (2018) and a +LSE in the DA conditions for Experiment 5. There was strong utilization of context and interitem association in Experiment 5 for both strong and weak items showing that even brief study attempts if presented many times, can still build context within a trace. Since the number of study attempts for items were so few in Sahakyan and Malmberg

---

**Figure 60.** Replication First Recall Probability

Strengthening context occurs through spacing items in study, but depending on the task, the number of repetitions that occurs is most important. Sahakyan and Malmberg (2018) spaced items twice which gave strong words only two attempts to potentially accrue contextual information. In contrast, Experiment 4 spaced all words three times and although weak words were presented very briefly (1 s), three separate storage attempts were enough to strengthen traces. Adding in cognitive load in the DA condition did disrupt overall recall, but the repetition of study seemed to protect words from missed storage attempts. Experiment 5 was similar to Sahakyan & Malmberg (2018) in that weak words were massed and strong spaced. However, weak words were massed once for a total of 6 seconds (rather than 12 s) and strong words were spaced 6 times for 1 s. The correct recall graphs were very different, in that there was a negative LSE in DA condition from Sahakyan and Malmberg (2018) and a +LSE in the DA conditions for Experiment 5. There was strong utilization of context and interitem association in Experiment 5 for both strong and weak items showing that even brief study attempts if presented many times, can still build context within a trace. Since the number of study attempts for items were so few in Sahakyan and Malmberg
(2018), with one attempt for weak items and two attempts for strong, the low probability of CRPs is explained by this restriction in building context-item and item-item information caused by fewer study attempts which strengthen traces.

![Graph](image)

**Figure 61.** Replication Conditional Recall Probability

*Note: Top row: weak words. Second row: strong words. Third row: mixed lists CRPs not separated by strength.*

The negative LSEs present in Experiment 6 are more than likely emerging from a different process than the negative LSE produced in the DA condition of Sahakyan and Malmberg (2018). The major difference in Experiment 6 between Experiment 4 and Sahakyan & Malmberg (2018) was the composition of mixed lists not blocking the presentation of weak and strong words. During study, a participant would not likely be able to predict the length of time the word was displayed in Experiment 6 mixed lists. This lack of predictability may have oriented their attention to next presented word in contrast to habituating to the speed at which words change on screen creating a situation where attention inevitably would wane. Additionally, the pattern of recall for these intramixed lists appears to be boosting weak items at the expense of mixed strong items. This interaction might occur if there was some increase of context information in weak traces, rather than weak traces being less likely to sample due to the presence of other strong traces.

The emergence of this pattern of recall when words are varied in study time can be explained when considering how subjective time is perceived and how it relates to the storage of information. Matthews and Heck
(2016) proposed a processing principle, which describes how the subjective duration of a stimulus is positively related to the vividness and clarity of its perceptual representation as well as the ease that information can be extracted from it. The authors compare and link research from early perceptual processing, working memory, and long-term memory that share these basic properties. Importantly, clearer and more vivid items appear to last longer to the subject, ultimately linking perceived duration to the amount of information that can be extracted (Matthews & Meck, 2016).

The subjective duration of a stimulus correlates with the strength of the neural area linked with the stimulus (Noguchi & Kakigi, 2006) and items that evoke greater neural responses are reportedly perceived longer in duration (Eagleman & Pariyadath, 2009). As participants studied the words on the intramixed lists, the changing of study time from word to word may orient their attention to the new word affecting the intensity of encoding. Since new or unexpected stimuli often draw cognitive processing resources (e.g., Meyer et al., 1991) and stimuli that attracted attention to another location expanded the participant’s subjective duration of the stimulus at this attended location (Yeshurun & Marom, 2008), attention grabbing stimuli that are perceived longer may be processed more thoroughly.

In contrast, pure and block-mixed lists present words in predictable and repeatable study times and may undergo repetition suppression. When stimuli are repeated, recent exposure reduces the neural response to a repeated item (e.g., Henson & Rugg, 2003) leading to localized reduction in vividness and subjective duration for similar stimuli (Matthews & Meck, 2016). Reducing vividness and subjective duration would ultimately reduce the amount of information that could be extracted. Additionally, this suppression increases as repeats become more common (Summerfield et al., 2008) which could reduce information extraction from massed items or items presented for the same amount of time successively. The reduced neural response from repetition suppression that occurs when repeats are common is thought to be from an implicit expectation that this stimulus will occur again (Summerfield et al., 2008). Even though the neural response decreases with common repetition, greater attention is also often given to novel stimuli, increasing the perceptual processing as well as the perceived duration of the first presentation (Rose & Summers, 1995; Tse et al., 2004). This greater processing and vividness might equate to both better contextual encoding as well as item information in memory traces, explaining the boosting effect of mixed weak traces in Experiment 6.
Spacing items out may counteract repetition suppression, as increasing the duration between the first and second presentation to 2 s is shown to counteract the usual shortening of the subjective duration (Matthews, 2015). Expectancy or predictions about upcoming stimuli interact with the repetition effect as well, such that increasing predictability about repeated items shortens their apparent duration (Matthews & Meck, 2016). However, in contrast to shortening apparent duration, the predictability between items indicates that the first item may be a good cue for the next, ultimately improving the perceptual strength of the stimulus (Matthews, 2015). This evidence for interitem associations forming has also been shown to be disrupted when dividing attention, as order performance was more affected than item performance when dividing attention in list tasks (Guitard & Cowan, 2022).

Although repetition suppression indicates a decrease in the perceptual processing, it does not mean that encoding stops, but that these patterns of perceived duration and strength of encoding describe some of the ongoing process in the discussed experiments. Drawing attention to a stimulus or enhancing its presence through novelty or unexpected presence shows to enhances the perception of information that can be extracted from it as well as the perceived amount of time that this extraction can occur. Repetition reduces novelty and subsequently the strength of the stimulus, but increased duration between repetitive presentations shows to reverse the effect of suppression. Adding in cognitive load, the amount of resources that are able to take part in the encoding process is diminished, ultimately affecting the amount of information that may be extracted. The setup of study also is important, as fewer spaced repetitions leads to a decreased ability to enhance traces that may have had only one other chance to store information but increasing the number of repetitions appears to protect from potentially missed or incomplete storage attempts.

How dividing attention impacts memory storage depends how the person is learning the information. The increase in cognitive strain while encoding does reduce later free recall, interitem associations are typically not heavily utilized in these conditions, and stored initial context is often decreased. Experiment 1-6 reinforced the idea that dividing attention affects storage of usable interitem associations because of the common effect of DA conditions often resembling conditions where interitem information was not strengthened (DO conditions). The replication free recall data supported the theory that strong words were not being strengthened during repeated study attempts, indicating that few repetitions are likely to increase the probability for a participant to miss a study attempt or store a very weak trace which may not be retrieved upon the second study attempt. Increasing study to 3 repetitions (Experiment 2, 4, and 3) and up to 6 (Experiment 5) protected from the severely
reduced trace DA affect, even when difficulty of the listening task was increased. The recognition replication produced a – LSE in the DA condition, bolstering the Sahakyan & Malmberg (2018) finding. This +LSE may indicate that in the divided attention condition, traces were less differentiated from each other whereas a -LSE in the FA condition indicates the presence of strengthened traces in memory. Experiment 6 revealed a way to produce a -LSE in free recall, hinting that weak traces were stored more strongly when mixed within strong items during study. Intramixing strength pattern maintained the – LSE in DA conditions as well, hinting at the importance of reducing the predictability of study that may prevent attentional waning.
References


### Table A1. Blocked Mixed Lists and Intramixed Lists

*Position refers to the original word order in the first time studied.

<table>
<thead>
<tr>
<th>Strength Blocked</th>
<th>Order</th>
<th>3 reps of 1-10</th>
<th>3 reps of 11-20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Word Position</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td>11 12 13 14 15 16 17 18 19 20</td>
<td></td>
</tr>
<tr>
<td>ML13</td>
<td>1 s</td>
<td>3 s</td>
<td></td>
</tr>
<tr>
<td>ML31</td>
<td>3 s</td>
<td>1 s</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intramixed Strength</th>
<th>Order</th>
<th>3 reps of 1-10 (1 rep for DO)</th>
<th>3 reps of 11-20 (1 rep for DO)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td>11 12 13 14 15 16 17 18 19 20</td>
</tr>
<tr>
<td>ML NB1</td>
<td>1 1 3s 3 3 3 3ls 3 1 ls</td>
<td>3s 1s 1s 3s 3s 3s 3s 3s 1s 1s</td>
<td></td>
</tr>
<tr>
<td>ML NB2</td>
<td>3 1 1s 3 3 3 3s 1 3 ls</td>
<td>1s 3s 1s 3s 1s 3s 3s 3s 1s 1s</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Different Order Intramixed Strength</th>
<th>Order2</th>
<th>1 repetition</th>
<th>1 repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position</td>
<td>3 8 2 5 1 7 1 0</td>
<td>3 8 2 5 1 7 1 0</td>
</tr>
<tr>
<td>ML NB1</td>
<td>3 3 1s 3 1 1s 1ls 3 1 ls</td>
<td>1s 3s 1s 3s 3s 3s 3s 3s 3s 3s</td>
<td></td>
</tr>
<tr>
<td>ML NB2</td>
<td>1 1 1s 3 3 3 3s 1 3 ls</td>
<td>1s 1s 3s 1s 3s 3s 3s 1s 3s 3s</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Different Order Intramixed Strength</th>
<th>Order3</th>
<th>1 repetition</th>
<th>1 repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position</td>
<td>3 1 1 0 2 9 5 8 6 4 7</td>
<td>3 1 10 2 9 5 8 6 4 7</td>
</tr>
<tr>
<td>ML NB1</td>
<td>3 1 1s 3 1 1s 3 3s 3 ls</td>
<td>1s 3s 1s 1s 1s 1s 3s 3s 3s 3s</td>
<td></td>
</tr>
<tr>
<td>ML NB2</td>
<td>3 3 1s 3 3 3 3s 1 3 ls</td>
<td>1s 1s 1s 3s 1s 1s 3s 3s 3s 3s</td>
<td></td>
</tr>
</tbody>
</table>
Figure A1. Full & Divided Attention Same Order Intramixed Design Serial Position

Note: Solid dots are strong words (3 s per presentation) & stars are weak words (1 s per presentation)

Left Column: Full Attention

Top Row: Intramixed List Version 1
Middle Row: Intramixed List Version 2
Bottom Row: Intramixed Lists Versions 1&2 Combined

Right Column: Divided Attention.
Figure A2. Full & Divided Attention Same Order Blocked-Mix Design Serial Position

Note: Solid dots are strong words (3 s per presentation) & stars are weak words (1 s per presentation)

Left Column: Full Attention
Right Column: Divided Attention.


Middle Row: Blocked-Mixed List Version 2

Figure 21. Exp 2 DO Blocked-Mix Pure Design Correct Recall
Note: A) DO Full Attention. B) DO Divided Attention.

Figure A3. Intramix-Pure Design Correct Recall
Note: A) DO Full Attention. B) DO Divided Attention.

Figure A4. DO Blocked-Mix vs Intramix Design Correct Recall
Note: A) DO Full Attention. B) DO Divided Attention.

Figure A5. DO Mix-Pure vs Intramixed-Pure Design CRP
Note: A) DO Full Attention. B) DO Divided Attention.
Figure A6. Different Order Intramix Lists Serial Recall

Note: Scatter plots display serial recall probabilities. Each column represents these probabilities plotted in the order of study for that particular repetition. Rows represent list type. Solid dots are strong words and stars are weak words.
Figure A7. Exp 2 compared to Exp 4 Correct Recall

Note: Top row is Full Attention. Bottom is Divided Attention. Lighter gray graphs display Experiment 2, darker gray displays Experiment 4.
Figure A8. Exp 2 compared to Exp 4 Pure Lists Serial Position

Note: Top row is Full Attention. Bottom is Divided Attention. Lighter gray graphs display Experiment 2, darker gray displays Experiment 4.

Figure A9. Exp 2 compared to Exp 4 Mixed Lists Serial Position

Note: Top row is Full Attention. Bottom is Divided Attention. Lighter gray graphs display Experiment 2, darker gray displays Experiment 4.
Figure A10. Exp 2 Compared to Exp 4 Pure Lists First Recall Probability

Note: Top row is Full Attention. Bottom is Divided Attention. Lighter gray graphs display Experiment 2, darker gray displays Experiment 4.

Figure A11. Exp 2 Compared to Exp 4 Mixed Lists First Recall Probability

Note: Top row is Full Attention. Bottom is Divided Attention. Lighter gray graphs display Experiment 2, darker gray displays Experiment 4.
**Figure A13.** Exp 2 Compared to Exp 4 Pure Lists Conditional Recall Probability

*Note: Top row is Full Attention. Bottom is Divided Attention. Lighter gray graphs display Experiment 2, darker gray displays Experiment 4.*

**Figure A12.** Exp 2 Compared to Exp 4 Mixed Lists Conditional Recall Probability

*Note: Top row is Full Attention. Bottom is Divided Attention. Lighter gray graphs display Experiment 2, darker gray displays Experiment 4.*
Appendix B:
IRB Exemption Letter

EXEMPT DETERMINATION

January 21, 2022
Anne Olsen

Dear Ms. Olsen:

On 1/21/2022, the IRB reviewed and approved the following protocol:

- Application Type: Initial Study
- IRB ID: STUDY003541
- Review Type: Exempt 2
- Title: Differential Attending before Remembering
- Funding: None
- Protocol: 3541 Protocol, Version #1, 01.13.22.docx

The IRB determined that this protocol meets the criteria for exemption from IRB review.

In conducting this protocol, you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Please note, as per USF policy, once the exempt determination is made, the application is closed in BullsIRB. This does not limit your ability to conduct the research. Any proposed or anticipated change to the study design that was previously declared exempt from IRB oversight must be submitted to the IRB as a new study prior to initiation of the change. However, administrative changes, including changes in research personnel, do not warrant a modification or new application.

Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities impact the exempt determination, please submit a new request to the IRB for a determination.

Institutional Review Boards / Research Integrity & Compliance
FWA No. 00001669
University of South Florida / 3702 Spectrum Blvd., Suite 165 / Tampa, FL 33612 / 813-974-5638

Figure 1. IRB Exemption Letter